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Exploiting Antarctic Mineral Resources-Technology, Economics, and the Environment

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Exploiting Antarctic Mineral Resources—Technology, Economics, and the Environment

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The author discusses the possibilities of exploiting mineral resources in the Antarctic. He analyzes those possibilities by examining the technological, economic and environmental tools which the Antarctic Treaty states would need in order to exploit resources in the unpredicatable and harsh climate of Antarctica.

I. INTRODUCTION

The possibility of exploiting what was thought to be vast mineral wealth in Antarctica has fascinated the public for generations—perhaps because people believed that any place so remote, so forbidding, and so difficult to work in must be possessed of great riches. Scientists and mineral resource experts have recognized that exploitation in Antarctica could only occur in the distant future, and national leaders have perceived that a disorderly competition to extract minerals would do serious damage to the environment of Antarctica and to scientific activity there.

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The Antarctic Treaty[1] ignores the mineral resource issue; indeed, had resources been dealt with, achieving agreement on the Treaty would probably have been impossible. Ignoring mineral resources was easier in 1959 than in the 1970's since recent technological advances for mineral extraction, particularly offshore oil, have made mineral exploitation a realistic possibility; recent advances have moved exploitation activities into new and very difficult areas in which to work, such as the North Sea and northern Alaska, which share many adverse characteristics with Antarctica. At the Seventh Antarctic Treaty Consultative Meeting in 1972, the Consultative Parties[2] felt that the mineral resource issue could no longer be deferred. The Consultative Meeting recommended that the subject "Antarctic Resources—Effects of Mineral Exploration" be placed on the agenda for the next Consultative Meeting. By the Eighth Consultative Meeting in 1975, the 1973 OPEC price increases made it clear that the pursuit of energy would become economic in frontier areas sooner than had been believed.

Energy resources are clearly the Antarctic mineral resources which are of primary concern. Only by some fluke would mineral resources other than oil and gas have a reasonable likelihood of being exploited in Antarctica in the foreseeable future.

The Eighth Consultative Meeting, held in Oslo in 1975, concentrated on the mineral resource issue, and one of its formal recommendations to the participating governments was to convene a special preparatory meeting the following year to deal with "Antarctic Resources—the Question of Mineral Resource Exploration and Exploitation," with a report to be made to the Ninth Consultative Meeting. This recommendation also suggested that a thorough study be made by participating governments of the environmental effects of such mineral resource activity in the Treaty area and included an invitation to the Scientific Committee on Antarctic Research (SCAR) to make an assessment of the environmental impact of mineral resource activity based on available information.

Following the 1975 Consultative Meeting, the Department of State, with a view toward meeting the requirements of the National Environmental Policy Act,[3] and supported by other United States government agencies interested in Antarctica, contracted with Ohio

1. The Antarctic Treaty, [1961] 12 U.S.T. 794, T.I.A.S. No. 4780, 402 U.N.T.S. 71 [hereinafter referred to as the Treaty].

2. The Consultative Parties are: Argentina, Australia, Belgium, Chile, France, Japan, New Zealand, Norway, South Africa, the U.S.S.R., the United Kingdom, the United States and, since 1977, Poland.

3. National Environmental Policy Act of 1969, §§ 2, 101-05, 201-07, 42 U.S.C. §§ 4331-35, 4341-47 (1970).

State University's Institute of Polar Studies to prepare a comprehensive scope paper for the Environmental Impact Statement that would be required if the United States moved into negotiations with its Antarctic Treaty partners on a mineral resource regime.

The 1976 Special Preparatory Meeting in Paris reviewed a SCAR document, "Antarctic Resources—Effects of Mineral Exploration," which was a preliminary response by SCAR to the invitation of the Eighth Consultative Meeting for a thorough environmental study. SCAR was urged to follow up with a more detailed assessment. It was further recognized at the meeting that a serious lack of information existed as to the technology suitable for mineral resource activity and for environmental protection in Antarctica. The Consultative Parties were advised to include experts in their delegations at the next Consultative Meeting to study questions of technology for mineral resource activity, to consider its impact on the Antarctic environment, and to suggest guidelines for preventing environmental damage and remedial techniques for cleanup.

This article draws extensively from three reports published in 1977. The first, *A Framework For Assessing Environmental Impacts of Possible Antarctic Mineral Development,*[4] is a two volume study prepared by experts at the Ohio State Institute of Polar Studies, under the direction of Dr. David W. Elliot. The second is the expanded SCAR report, *A Preliminary Assessment of the Environmental Impact of Mineral Exploration/Exploitation in Antarctica,* prepared by the Group of Specialists on the Environmental Impact Assessment of Mineral Exploration/Exploitation in Antarctica,[5] chaired by Dr. J.H. Zumberge of the United States. The third is part of the formal report of the Ninth Consultative Meeting, *The Report of the Group of Experts on Mineral Exploration and Exploitation,*[6] chaired by Dr. Martin Holdgate of the United Kingdom.

II. THE MINERAL RESOURCE POTENTIAL

Abundance and price are critical factors in judging whether commercial mineral resource exploration and exploitation will be

4. INSTITUTE OF POLAR STUDIES, A FRAMEWORK FOR ASSESSING ENVIRONMENTAL IMPACTS OF POSSIBLE ANTARCTIC MINERAL DEVELOPMENT (P. I 1977) [hereinafter cited as FRAMEWORK].

5. GROUP OF SPECIALISTS ON THE ENVIRONMENTAL IMPACT ASSESSMENT OF MINERAL EXPLORATION/EXPLOITATION IN ANTARCTICA (EAMREA), THE SCIENTIFIC COMMITTEE ON ANTARCTIC RESEARCH, A PRELIMINARY ASSESSMENT OF THE ENVIRONMENTAL IMPACT OF MINERAL EXPLORATION/EXPLOITATION IN ANTARCTICA (1977) [hereinafter cited as SCAR Report].

6. *Report of the Group of Experts on Mineral Exploration and Exploitation,* Antarctic Treaty Ninth Consultative Meeting, ANT/IX/51 (REV. I) (Agenda Item 5) (Sept. 29, 1977) [hereinafter cited as *Experts' Report*].

undertaken. No organization is likely to search for mineral deposits in a particular region unless it believes that minerals found there can be delivered economically to a point of consumption in the near future. The problems and expenses of Antarctic operations are sure that only the proven existence of a large mineral deposit of great value could justify the costs of development, production and transport.

Except for a few small areas, the geology of Antarctica is not known in detail. Few of the known mineral occurrences have sufficient size and grade[7] to attract much attention, even if located in the more accessible regions. Thus, an assessment of where mineral deposits are likely to occur must be based on geological theories about the distribution of mineral deposits and consideration of the major geological provinces of Antarctica.

Almost all of the Antarctic continent is mantled by an ice sheet, and, because of the problems posed for mineral discovery and development, it appears highly unlikely that minerals under the ice sheet would be exploited. While substantial quantities of minerals have been noted in the course of scientific investigation in ice-free areas, problems of overland transport to ports would be enormous if these areas were exploited. Virtually all hard mineral production requires large quantities of fresh water, a costly commodity in Antarctica. Furthermore, an adequate labor force would be extremely expensive to maintain.

All of the minerals found on land in Antarctica are also found in more temperate areas in some abundance. There is no apparent incentive for exploiting them in Antarctica. A report prepared within the United States government,[8] tabled at the 1976 Paris Special Preparatory Meeting concluded that:

> [T]he economics of exploration, extraction, and transportation in the land areas are such that no industrial exploitation of most hard minerals appears likely in the foreseeable future. It is possible that if large high-grade deposits of rocks containing high value metals such as platinum or chromium were discovered in relatively accessible areas, it might be economically feasible to exploit them. Among the mineral occurrences discovered, only iron and coal have actually been found in quantity. However, the low grade and remote location of the iron and coal have made exploitation economically unfeasible, even in the case of coal for local use.[9]

7. The grade of a mineral occurrence is the relative quantity or percentage of ore-mineral content in the particular deposit. This percentage must be sufficiently high to make extraction economically feasible.

8. U.S. Gov't Report tabled at 1976 Paris Special Preparatory Meeting.

9. *Id.*

Further discussion in this article of onshore hard minerals does not seem worthwhile. Except for minerals such as sand and rock, which might be used in construction of bases onshore or production facilities offshore, there seems to be little likelihood of exploitation of such minerals.

Onshore petroleum resources, according to the United States Geological Survey, can also be eliminated from consideration since the nature of the sedimentary rocks projecting through the ice cap on land are indicative of conditions which are not conducive to the preservation of oil and gas.[10] Offshore, manganese nodules do occur, but those on the Antarctic seabed have significantly less valuable metal content than nodules found closer to the Equator. They are considered not to be of commercial interest for the foreseeable future.[11]

With respect to offshore hydrocarbons, the United States report tabled in Paris stated:

> Interpretation of the geologic and geophysical data so far accumulated indicates a good probability that quantities of oil or gas or both are present in the Antarctic continental shelf. At the same time, these data are insufficient to establish the probabilities of occurrence of economically recoverable deposits of petroleum. The combination of water depth, ice conditions, severe weather, transportation costs, and short annual working time imply production costs of such magnitude that other areas will be more attractive to industrial exploitation for some time, given current assumptions on the economics of hydrocarbon development.[12]

In describing hydrocarbon possibilities, the report states that methane and ethane have been encountered in stratigraphic drilling in the Antarctic continental shelf under the Ross Sea, but information from various scientific projects studying the geologic origins of Antarctica, as well as some geophysical surveys, is insufficient to determine the existence of hydrocarbons in commercially interesting quantities. Pending the evaluation of the results of the extensive seismic, magnetic and gravity surveys which would have to be run, numerical estimates would be only order of magnitude guesses. The report concludes:

> With these caveats in mind, it appears that the Antarctic continental shelf could contain potentially recoverable oil in the order of magnitude of tens of billions of barrels, but it is less likely that

10. U.S. Dep't of the Interior, Geological Survey Circular No. 705, Mineral Resources of Antarctica 15 (1974).

11. *Id.* at 12.

12. U.S. Gov't Report, *supra* note 8.

no potentially recoverable resources occur or that even larger amounts exist. The most prospective areas indicated by present knowledge are the Mesozoic section of the Weddel Sea Basin, the Cenozoic portions of the Ross Sea Basin underlying the Amery Ice Shelf, the Bellingshausen Sea, and the Scotia Sea.[13]

III. THE OPERATING ENVIRONMENT FOR MINERAL ACTIVITY

In several parts of the world, oil and gas activities are carried on under extremely adverse conditions, such as the drilling off Labrador and the production in the North Sea and at Prudhoe Bay. None of these, however, is as challenging as Antarctica.

Antarctica is an isolated continent, centered on the South Pole and surrounded by a continuous deep ocean. It is the coldest, highest, windiest continent on Earth, about one and one-half times the size of the continental United States, excluding Alaska. There are deep continental shelves. In addition, it is physically isolated by a pack ice belt extending from 500 to 1,500 kilometers (300 to 900 miles) out from the continent.[14]

The climate is more severe than in the Arctic. Not only are the surface waters of the Southern Ocean very cold, but the air temperatures over the continent are also extremely frigid, with the temperatures in coastal regions ranging from a mean of 0° C. (32° F.) in summer to a mean of -18° to -29° C. (0° to -20° F.) in winter. The interior is much colder with a mean temperature as low as -68° C. (-90° F.). The Antarctic Peninsula has a milder climate. In relation to environmental impacts, low temperatures can be both adverse and beneficial; biodegradation of toxic materials is slower than in temperate regions, but Antarctic organisms have slower growth rates and are likely to incorporate toxic materials in their tissues more slowly.[15]

About ninety-eight percent of the continent is permanently covered by snow and ice. Some areas of exposed rock and rock debris occur in coastal areas, but apart from the Dry Valleys and other ice-free valleys of East Antarctica, it is uncommon for such areas to cover more than a square mile at any one locality, even in summer.[16] Good sites for resource-related shore installations are scarce.

The Antarctic continental shelf is relatively narrow and deep; much of it is covered by ice shelves and grounded ice. The ice shelves constitute about eleven percent of the Antarctic area. They

13. *Id.*
14. FRAMEWORK, *supra* 4, at ii-1.
15. SCAR Report, *supra* note 5, at 26-27.
16. FRAMEWORK, *supra* note 4, at ii-3.

are composed of fresh water flowing down from the interior of the continent and coalescing into extensive shelves floating on the Antarctic seas. Those ice shelves may be as thick as 460 meters (1,500 feet), but are more typically 245 meters (800 feet) thick. These shelves "calve"[17] into tabular icebergs of comparable thickness, and up to 160 by 70 kilometers (96 by 43 miles) in size. Their draft may be up to 490 meters (1,600 feet). They are much bigger than Arctic icebergs and move at about ten nautical miles per day, posing a threat to shipping and marine installations, though satellites and radar greatly facilitate their tracking.[18]

The continent is surrounded by salt-water pack ice, extending to a maximum of 500 to 1,500 kilometers (300 to 900 miles) from the continental coast. It achieves maximum area in September and normally occupies less than one-fifth of that area by March. The floes which compose the pack ice are usually 9 to 90 meters (30 to 300 feet) across and up to 3 meters (10 feet) thick near the outer edge of the pack. They are lighter than those in the Arctic because of the great seasonal fluctuation. The ice drifts northward and melts in the spring and summer, making most floes in Antarctica less than a year old. Prevailing Antarctic winds tend to disperse the floes away from the continent in contrast to winds in the Arctic which confine the ice to the Arctic basin, creating multiyear floes.[19]

Antarctic winds are impressive in their velocity and unpredictability. Frequent weather systems are generated in the circumpolar belt between latitude 60° S. and latitude 70° S., resulting in strong westerly winds on the northern flank. The surface flow of sinking cold air from the interior produces violent katabatic winds in the coastal areas moving northwards from the continent, which diminish and change dramatically a few miles from the coast. In certain areas they commonly exceed seventy knots for many hours.[20] Their violence and the succession of cyclonic storms are particularly dangerous to navigation because of the presence of icebergs and ice floes, because of the accumulation of ice on ships' superstructures increasing the danger of capsizing and because of the wide separation of weather stations needed for accurate forecasting.[21]

17. The process of calving is the breaking away of a mass of ice from an ice shelf, glacier or iceberg to form a new iceberg.

18. FRAMEWORK, *supra* note 4, at v-20.

19. *Id.* at ii-8. "Floes" are large sheets of floating ice formed on the surface of a sea or other body of water. They are not the same as ice shelves which are fresh water made up of ice flowing outward toward the sea from the interior of the continent itself and are attached to land on one side.

20. *Id.* at ii-14.

21. SCAR Report, *supra* note 5, at 31.

The major Antarctic current, the Circumpolar, tends to move in a clockwise direction around the continent with a velocity of about one mile per hour. In coastal areas, however, the current flow tends to be in the opposite direction.[22]

Antarctic water and shore areas include many species of fauna which may be affected by mineral resource activities. The nutrient-rich upwelling waters at the Antarctic Divergence are very productive, and the food chain begins with phytoplankton, consumed by copepods and krill, which in turn are consumed by birds, seals, whales and squid. Fish are a relatively small component of the marine ecosystem. The major krill grounds appear to be the Weddell Sea, the Amundsen Sea and off the Wilkes coast. Krill appear to have the most promising potential for commercial harvesting, which is believed to have the capability of almost doubling the present world catch of fish and shellfish. Whales, many of which feed on krill, have been drastically reduced in abundance by commercial exploitation, but their numbers are increasing. Fifty species of birds breed on the Antarctic continent and offshore islands, deriving nearly all their food supply from the ocean, with krill being apparently a major source.[23]

IV. THE PHASES OF OFFSHORE HYDROCARBON ACTIVITY[24]

Though only a small proportion of scientific research leads to commercial resource activity, most modern quests for resources, whether living or nonliving, have scientific research as their first phase. In the first phase of a quest for hydrocarbons, governments or research organizations study geological processes, examine the formation of mineral deposits and assess the hypothetical resources through geologic and geophysicial mapping and statistical analysis. Scientific research may be accomplished by ships or aircraft owned or operated by governments, research institutions or commercial firms. Tests for scientific research, as distinguished from commercial resource activity, include recognition of scientific objectives, publication of data and results and wide participation in planning and execution of research.

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22. FRAMEWORK, *supra* note 4, at ii-14.

23. *Id.* at viii-ix.

24. This section is based on the following sources which should be consulted for further details: WOODS HOLE OCEANOGRAPHIC INSTITUTION, EFFECTS ON COMMERCIAL FISHING OF PETROLEUM DEVELOPMENT OFF THE NORTHEASTERN UNITED STATES (1976) [hereinafter cited as WOODS HOLE]; EXXON PRODUCTION RESEARCH COMPANY, EXXON CORPORATION, DEEPWATER CAPABILITIES (1976) [hereinafter cited as EXXON]; SHELL BRIEFING SERVICE, SHELL INTERNATIONAL PETROLEUM COMPANY LIMITED, SUBSEA TECHNOLOGY (1977) [hereinafter cited as SHELL].

In early phases of hydrocarbon exploration, research ships normally tow a string of instruments for seismic, magnetic and gravity surveying.[25] Some magnetic and gravity surveys may be done by aircraft.[26] Detailed surveys examine promising locations discovered earlier and may include bottom samples and cores.

Drilling may accompany scientific research, such as the Deep Sea Drilling Project[27] with multinational financing and participation, or it may be a part of commercial exploration. Exploratory drilling involves a quantum jump in both expense and risk of damage over previous phases. No other means exists to determine whether commercial accumulations of oil or gas are present. Usually more than one hole is drilled to determine the nature of the structure and the size of the field. Drill ships, semi-submersibles, jack-up rigs or submersible barges may be used, but jack-up rigs and submersible barges are limited to shallow waters.[28] The hole is drilled with a rotating bit at the bottom of a string of drill pipe, with drilling mud circulated through the string to remove cuttings. The mud also helps control pressure in the hole, together with steel pipe casing and mechanical blowout preventers. Exploratory holes are rarely used for production but are plugged with cement and mechanical plugs, and new holes drilled for producing wells. Many holes must be drilled; historically on land, some oil is found in approximately one hole in ten, commercial quantities in about one hole in fifty.[29]

When a commercial reserve has been discovered and the extent of the field has been determined, one or more permanent production platforms are placed within the field. These may consist of steel truss structures attached to the ocean floor by steel pilings, concrete gravity platforms held in place by their own weight or subsea production systems where the entire mechanism is located on the ocean floor, with drilling accomplished by a surface drillship. A single large platform may cover two and one-half acres of ocean; numerous wells may be drilled from it, some nearly three kilometers (two miles) from the platform at their farthest extent.[30]

Production systems, involving various processing operations, are expected to remain in place for the life of the field—twenty or thirty years. Gas is normally found in addition to oil and may be

25. WOODS HOLE, *supra* note 24, at 57; *see* EXXON, *supra* note 24, at 2.

26. *See Expert's Report, supra* note 6, § II, paras. 8, 9.

27. EXXON, *supra* note 24, at 13.

28. *Id.* at 16-19; FRAMEWORK, *supra* note 4, at iv-20; WOODS HOLE, *supra* note 24, at 58-59. *See also* SHELL, *supra* note 24, at 1.

29. WOODS HOLE, *supra* note 24, at 58-59.

30. *Id.* at 60-61.

extracted either together with oil production or from wells for gas alone. It may be burned ("flared"), used for energy at the production site, shut in and held for future use, reinjected into the field to maintain pressure and increase oil yield, piped to consumers elsewhere or liquefied and moved to market in tankships.[31]

A network of gather lines is needed to collect the petroleum from the various production platforms and to transport it to storage or to other processing platforms.[32] If storage is onshore, trunk pipelines must be laid. Floating storage tankers are used in the North Sea, as well as floating storage and production platforms.[33]

V. Commercial Exploration Prior to Drilling

Many believe that the start of *any* commercial activity related to oil and gas in Antarctica would inspire greed for petroleum wealth which would put severe strain on the Treaty.[34] This precarious first stage is identified by the Group of Experts as "basic exploration, which involves many activities inseparable from those in normal scientific, geological, and geophysical research and seeks to define the structures of the strata most promising for detailed examination."[35] They concluded that there is nothing to prevent basic exploration at this time and referred to a number of methods in current use. Bathymetric surveys and geological sampling would use conventional ship-based techniques. Aeromagnetic techniques are particularly appropriate in searching for basins containing substantial thicknesses of sediment. Water samples taken just above the seabed in searching for traces of hydrocarbon seepage provide another environmentally safe technological tool as a supplement to seismic studies.[36]

Despite the problems of sea ice, reflection methods of seismic survey now widely used in the petroleum industry can be utilized in many parts of the Antarctic at certain seasons. Reflection methods, such as multichannel arrays and nonexplosive air gun energy systems, can give penetration of the seabed up to ten to fifteen kilometers (6.2 to 9.3 miles), which is sufficient for exploration without a damaging impact on marine fauna and flora. Refraction methods are also useful in commercial operations to a limited degree for additional velocity information, using air guns or occasionally high

31. *Id.* at 62.
32. *Id.* at 63. *See also* Exxon, *supra* note 24, at 23, 28-31.
33. Framework, *supra* note 4, at iv-22,-23; *Experts' Report, supra* note 6, § II, para. 24.
34. SCAR, *supra* note 5, at 22.
35. *Experts' Report, supra* note 6, § II, para. 2.
36. *Id.* paras. 8, 9.

explosives.[37] Explosives were not considered by the Experts as essential for offshore resource exploration.

Arrays of sensors, which give more reliable results, are more troublesome in ice conditions. Therefore, the Elliot report concluded that light pack ice ships could use seismic profilers or sonoprobes. Under heavy pack ice conditions, surveys might be conducted from a submersible, or surface ships could operate in leads in the ice.[38] Because of the need to learn more about the structure of the land mass and continental margin of Antarctica before exploratory drilling can be considered, the Group of Experts determined that while satisfactory geophysical methods are available for scientific exploration and search for minerals in Antarctica, an extended exploratory phase is likely.[39]

VI. DRILLING

Considerable expertise and experience exist in offshore drilling methods suitable for depths up to 300 meters (985 feet) and under rigorous conditions like those of the North Sea. But that is not true concerning Antarctic seas involving large icebergs. Arctic drilling experience is of some value, but Antarctic conditions are very different. In comparison to the Arctic, Antarctica has lighter pack ice cover, but it also has icebergs which are on a larger order of magnitude and far more numerous. Furthermore, Antarctic shelf depths are much greater. Water depths of 500 meters (1,640 feet), which are commonly found, require that dynamically positioned or moored drilling platforms be used.[40]

In the 1972-73 season, the scientific drillship *Glomar Challenger* drilled into the continental shelf of the Ross Sea at several locations, and traces of methane and ethane were found in three of the four holes. (This did not prove the presence of exploitable hydrocarbons but did generate interest in further exploration of that area.)[41] The Experts' Report states that it is important to discriminate between shallow seabed drilling for geological samples for scientific purposes and exploratory drilling for hydrocarbons. The latter requires blowout preventers and other safety devices, while the former may not.[42]

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37. *Id.* paras. 10, 11. They did agree, however, that the use of explosives is unavoidable in certain geophysical studies of deep structures. *Id.* para. 11.

38. FRAMEWORK, *supra* note 4, at iv-19.

39. *Experts' Report*, *supra* note 6, § II, para. 12.

40. FRAMEWORK, *supra* note 4, at iv-20.

41. SCAR Report, *supra* note 5, at 19.

42. *Experts' Report*, *supra* note 6, § II, para. 15.

Technology already exists, according to the Experts, for drilling from dynamically positioned mobile structures in depths below 1,000 meters (3,280 feet). Such drilling would be theoretically possible in the Antarctic in areas free of ice where massive icebergs are infrequent for at least three months in the summer. Such sites, however, are rare and are limited in extent.[43]

The Experts noted the existence of technology, such as large floating caisson structures, which allows drilling in deeper waters and in Arctic areas covered with pack ice throughout the year. Such technology might be adapted to exploration of larger Antarctic margin areas but not to conditions below the thick ice shelves.[44] A dynamically positioned drillship, the *Pelican*, was utilized in Labrador.[45] Such a ship, or a floating dynamically-positioned structure could be used in Antarctica. There are important differences, however, between Arctic conditions and those in the Antarctic, particularly with respect to the greater size and persistence of Antarctic icebergs. While the Labrador experience has confirmed that towing can be used to change the direction or drift of smaller icebergs in order to cut roughly in half the occurrences necessitating disconnection of the drillship from the borehole, the benefits of this technique may be less in Antarctica.[46]

Because of the harsh Antarctic climatic conditions, including the continual threat of icebergs, it is essential that drilling operations utilize existing technology for shutting down, disconnecting from the drill site, and reentering later without the risk of pollution.[47] Advance data concerning iceberg movement would facilitate this process. In summarizing the status of drilling technology, the Experts concluded:

> Existing technology does not appear suitable for exploratory drilling in those parts of the Antarctic seas covered almost throughout the year by pack and fast ice of many years' accumulation or by floating ice shelves and glaciers. For these reasons most of the seas on the Antarctic margin are inaccessible for exploratory drilling at present, and fixed or floating platforms of the kind used in oil exploitation today seem equally unsuited to these areas. Technology permitting drilling from installations on the seabed in other regions is being developed and may help to overcome this obstacle except in those areas where icebergs ground on the sea bed. Advances are also being made in the

43. *Id.* para. 16.
44. *Id.* para. 17.
45. *Id.* para. 18.
46. *Id.* para. 19.
47. *Id.* para. 20.

> design of systems both for drilling and operating production wells on or below the sea bed in deep waters. The water depth presents no inherent problem because such systems would be unmanned and their maintenance would be likely to be undertaken by submarines rather than divers. Such systems have not yet been developed for the conditions prevailing in the Antarctic.[48]

The Experts could not entirely agree as to the earliest time at which exploratory drilling might begin, but none expected it to occur in less than five years and most considered it unlikely in less than ten years.[49]

VII. Production Technologies

Concerning recent developments in production installations, the Experts concluded:

> At present several kinds of platform are used in oil exploitation at sea. Fixed structures of concrete or steel are being used today in depths of water down to 130 and 300 m[eters] respectively, and have been developed for safe operation even in seismic zones. One floating platform, linked by risers to production wells, is in use in the North Sea. About 100 underwater well head systems are in use, mainly in shallow water and none below 300 m[eters]. Despite considerable advances in the design of platforms, risers (the link between ocean floor and surface platform) and safety devices, none of these platform systems is suitable in their present form for installation in the Antarctic. While considerable progress has been made in developing surface platforms to withstand storms, and pack ice, none is proof against icebergs on an Antarctic scale. At the present, the design of equipment for use in oil exploitation in the Antarctic remains in the conceptual stage.[50]

Most production emerging from wells is a mixture of liquid hydrocarbons, gas and water. Normally, these are separated, and the gas and water may be injected back into the reservoir to maintain pressure and to assist further exploitation. Existing separation and reinjection technology could be used in any fixed or floating production platform and has been developed and tested for seabed structures suitable for Antarctic subsea use. Gas, when separated from the oil, could also be used to fuel drilling and other production operations. The Experts advised against the use of flaring in Antarc-

48. *Id.* para. 23.
49. *Id.* para. 5.
50. *Id.* para. 24. The *Experts' Report* unintentionally classes underwater wellhead systems with platforms, which they are not.

tic operations. To liquefy the separated gas for removal and marketing would be difficult under Antarctic conditions. Liquefacation would require complex facilities, afloat or ashore, vulnerable to ice and weather if floating and requiring long pipe runs if ashore.[51]

Recent developments in subsea production systems appear to hold the greatest promise for future development of hydrocarbon resources in Antarctica because wellheads can be placed on the ocean floor, possibly in protective silos to guard against iceberg scour, with connecting pipelines to platforms or other storage facilities.[52]

VIII. STORAGE

Offshore Antarctic drilling installations would require larger oil storage capacity than in other parts of the world because the harsh environment would inevitably affect shipping operations.[53] Even subsea installations loading into submarine tankers would require considerable capacity.[54]

Oil might be piped ashore for storage, but pipelines would have to be buried in many locations to protect against "iceberg scour."[55] Storage at the production site could be on the ocean floor or at floating terminals, but icebergs would be a constant threat with either location. Large submerged storage tanks are in use in the Persian Gulf and the North Sea, and various kinds of floating terminals are in use. Ice-resistant floating terminals have been suggested for use in the Arctic, where oil would be loaded into tankers during periods of thaw.[56] The use of large flexible bladders, such as those used to store small quantities of fuel for aircraft operations in Antarctica, has also been proposed.

IX. TRANSPORTATION

Ships modified to travel through ice fields in Antarctica and perhaps specially designed submarines, will be needed to support

51. *Id.* paras. 30-32.

52. FRAMEWORK, *supra* note 4, at v-21.

53. FRAMEWORK, *supra* note 4, at v-22. Dr. Elliot suggests that any oil produced from an Antarctic field would have to be transported during the three-month summer; he also notes that the low temperatures would make the crude oil flow slower and harder to pump. *Id.*

54. *Experts' Report*, *supra* note 6, § II, para. 32.

55. "Iceberg scour" is the gouging out of the seabed by the bottoms of passing icebergs. The danger exists at depths of less than 300 meters (1,000 feet) and would require pipelines or undersea storage facilities to be buried beneath the seabed. Scouring up to 6 meters (20 feet) in depth is expected in the shallow waters of the Arctic, and Antarctic icebergs are larger. FRAMEWORK, *supra* note 4, at iv-21, -23 to -24.

56. *Id.* at iv-23. Floating terminals would require icebreaking capability and would have to be moored to the ocean floor. *Id.*

offshore oil installations. Present technology appears adequate for the transportation or personnel and supplies, but development of methods to transport crude oil from the area is needed. The Experts' report suggested:

> It seems likely that separated oil would be loaded directly into ships at installations at sea for removal from the Antarctic. Either specially designed surface vessels or submarines could be used to remove oil. Information obtained during the voyage of the "Manhattan"[57] may allow the design of tankers that could operate commercially through Arctic pack ice. The attraction of submarines lies in their greater certainty of year-round access. The concepts behind the design of both types of vessel are being explored actively, and it is likely that technology would be available by the time Antarctic oil exploitation became possible on other grounds. Pipelines, however, provide a third option. Their use is unlikely in many parts of the Antarctic, especially because of iceberg scour but also because there is little attraction in removing oil from the open sea to coastal areas which might be no more easily accessible by tanker; modern techniques of tunnelling in the sea floor at depths of up to 300 meters could possibly be developed to the point where pipelines could be adequately protected.[58]

Tanker technology is relatively advanced compared to some other elements of the possible Antarctic exploitation system. Dome Petroleum of Canada has proposed transporting oil more than 7,240 kilometers (4,500 miles) from the Beaufort Sea to the East Coast of the United States on a year-round basis, using 200,000 deadweight-ton tankers and an advanced type of icebreaker.[59] Petro-Canada's Arctic Pilot Project proposes shipping liquefied natural gas (LNG) from Melville Island, east of the Beaufort Sea via the Northwest Passage to the eastern seaboard of Canada, using LNG tankers led by icebreakers.[60]

X. Pollution Prevention and Cleanup

Preventing pollution rather than cleaning it up was stressed by the Experts, since cleanup presents formidable problems in Antarctic conditions. They considered existing technologies for pollution prevention to be in need of refinement, suggesting that highly-

57. The *Manhattan*, a tanker modified to travel through ice fields, was damaged during a trip to Prudhoe Bay. *Id.* at vii-27.
58. *Experts' Report, supra* note 6, § II, para. 35.
59. Dome Petroleum Limited, *Marine Delivery Systems for Alaskan Offshore Oil and Gas* (Jan. 1978).
60. Petro-Canada, Arctic Pilot Project (1977).

trained personnel and careful safety procedures be developed, as well as risk analyses.[61]

The Experts paid particular attention to the human factor, calling for intensive training and frequent refresher courses. They viewed the risk of human errors in Antarctica to be no greater than elsewhere and assigned a small risk to blowouts, with the use of sound technology, intensive training and vigilant personnel.[62]

They thought it likely that a major risk of spills would occur in the transfer from production wells to storage and then to tankers.[63] Tankers would need to be specially built, with multiple and advanced safety and pollution control features. If tanker terminals were built onshore at any of the few suitable sites, special arrangements and standards would be required for handling bilge and ballast water.[64]

The Experts believed that oil spilled at sea, particularly where there were high winds, waves or ice, would probably be impossible to recover or even to contain using present technology.[65] This conclusion is supported by a recent Canadian government study dealing with the Arctic, which concluded that currently available oil spill countermeasure techniques generally have limited effectiveness in the Arctic offshore areas.[66]

XI. Impact on the Antarctic Environment

Concern for the environment is implicit in the Antarctic Treaty,[67] although environment is not mentioned in the Treaty itself.[68] Not until the Sixth Consultative Meeting in 1970 did a recommendation to governments specifically address environmental protection, though earlier meetings had dealt with such environmental matters as flora, fauna and specially protected areas.[69] The clear

61. *Experts' Report, supra* note 6, § II, paras. 43-58.

62. *Id.*

63. For a discussion of the legal aspects of oil pollution from tankers, see *The 1973 IMCO Convention: Tightening Controls on Operational Oil Pollution from Tankers*, 5 U.C.L.A.-Alas. L. Rev. 353 (1976).

64. *Experts' Report, supra* note 6, § II, para. 54.

65. *Id.* para. 58.

66. Thornton, *Arctic Offshore Oil Spill Countermeasures with Emphasis on an Oil and Gas Blowout in the Southern Beaufort Sea*, in Proceedings, 1977 Oil Spill Conference 318 (Am. Petroleum Inst. 1977).

67. The Antarctic Treaty, *supra* note 1.

68. The Treaty prohibits nuclear explosions and disposal of radioactive materials on the continent. *Id.* art. IV(1).

69. Recommendations of the Sixth Antarctic Treaty Consultative Meeting, Oct. 30, 1970, Recommendation VI-4, [1974] 25 U.S.T. 266, T.I.A.S. No. 7796.

The members of the meeting recognized that the Antarctic ecosystem is susceptible to human interference, and called for research on man's impact on the continent and for the thrust of the Treaty's concern for effective scientific research implies that the Antarctic Treaty area should be preserved in a natural state, as undisturbed as possible by man's activities.[70] There is also great popular appeal in not allowing the scars, stains and refuse of human activity to spoil the natural beauty of Antarctica. Both scientific and esthetic concerns have caused environmental protection to become a highly politicized and potentially emotional issue, one which may be manipulated by Treaty states or by others to prevent or limit commercial mineral resource activity for reasons quite unrelated to the environment.

The Experts recognized that they could not thoroughly study the impact of mineral activity on the environment of Antarctica and noted that the subject had not yet received adequate study.[71] They took note of the SCAR report,[72] the Elliot report,[73] and other papers, considering them a useful starting point for more complete appraisal and for designing a program for developing more precise assessments. They identified an urgent need for further studies related to the environment, particularly for detailed studies of those areas most likely to be exploited. Necessary work included the following: research on weather, ice and current; study of the fundamental structure and functioning of those parts of the Antarctic ecosystem most likely to be affected by mining and drilling; baseline studies on levels of hydrocarbons and other substances in plants and animals; research on effects of possible pollutants on important organisms such as krill; and research on the biodegradation of oil and other pollutants.[74]

Although there is a lack of environmental knowledge and a clear need for additional studies, some useful preliminary judgments on the nature of environmental impacts from mineral resource activity can be summarized from the SCAR and Elliot reports.

A. *On-Land Activity*

Whether as logistic support for offshore activity or for obtaining construction materials such as sand and gravel, on-land activity is bound to have significant impacts in a limited number of onshore

reduction of known causes that interfere with the environment. *Id.*

70. The members of the meeting invited proposals for the control of radio isotopes used in experiments to minimize its harmful impact on the Antarctic environment. *Id.* at Recommendation VI-5.

71. *Experts' Report, supra* note 6, § II, para. 36.

72. *See* SCAR Report, *supra* note 5.

73. *See* FRAMEWORK, *supra* note 4.

74. *Experts' Report, supra* note 6, § II, paras. 36-39.

areas, particularly where major terrain modification is involved. Any construction on land will affect the environment, particularly when excavating is involved. The onshore construction of piers, tank farms, pipelines, housing and airfields could change the permafrost, drainage patterns, animal life and the natural beauty of the landscape because of man-caused dust, exhaust, spills, sewage and refuse.[75]

B. *Most Likely Sources of Significant Pollution by Oil*

An accident during drilling or production could spill large quantities of oil into Antarctic waters. Adequate surveys conducted before drilling and the use of blowout preventers should reduce the chances of a blowout or a large spill. The harsh environment could, however, increase the time needed to bring a blowout under control. A blowout which could not be contained because of severe end-of-season weather could discharge large quantities of crude oil into the Southern Ocean, with possibly disastrous consequences.[76]

Spills can result from accidents to tankers or pipelines, or from discharges from loading, tank washing or other operational causes. Strict regulation and use of modern technology can virtually eliminate discharges from tank washing and keep other operational discharges at a minimal level. But there is still a serious possibility of a major spill from a tanker accident in this region of strong storms, severe ice and large icebergs. Although weather forecasting and the tracking of large icebergs have been made a great deal easier by weather satellites and other advanced techniques such as shipboard radar, the threat remains, particularly from small icebergs and ice floes which although difficult to detect would still be dangerous to tankers.[77]

C. *Effects of Oil Pollution*

Oil from a large spill could affect numerous organisms, and the effects could travel to all levels of the marine ecosystem. The oil would degrade more slowly than in warmer areas. Birds, mammals and fish would be affected, with a more severe impact if the spill moved into coastal waters. The hydrocarbons are likely to affect

75. FRAMEWORK, *supra* note 4, at vii-10; SCAR, *supra* note 5, at 47. Underground waste disposal alone could foul the subsurface because of the low rate of bacteriological activity in the cold. *Id.*

76. FRAMEWORK, *supra* note 4, at vii-26. If a spill occurs on land, light hydrocarbons such as gasoline would evaporate, but crude oil might solidify, possibly forming a tarry cap which would trap the more volatile components. *Id.* at vi-19.

77. *Id.* at vii-27 to -28.

local phytoplankton, zooplankton and fish, and indirectly affect the animals which feed upon them. Birds could suffer oiling of feathers, seals could have ill effects from ingesting oil, and fur seals could lose buoyancy from fur oiling.[78]

Though local impacts may be severe and often irreversible, the overall effect may not be significant because the area involved in the spill is likely to be quite small in relation to the ocean area of Antarctica. (The Gulf of Mexico has less than five percent of the area of the Southern Ocean south of Antarctic Convergence.) Even a major blowout of 40,000 barrels of oil at a thickness of 0.1 millimeter (0.004 inches) would cover continuously only 80 square kilometers (50 square miles) or a circle 10 kilometers (6.2 miles) in diameter. Colder conditions would produce a thicker film, with a smaller area of coverage, though biodegradation would proceed more slowly.[79] A major tanker spill, however, might be much larger.

D. *Other Impacts*

Flaring of gas would raise hydrocarbon levels in the air or water.[80] Also the construction of drilling structures, seabed production facilities and pipelines would have severe but localized effects on the seabed, not unlike those from iceberg scour.[81]

XII. GUIDELINES

The Experts drew on their technological appraisal, the environmental background, and their expertise in resource operations to prepare a series of guidelines which should be observed for mineral resource activity. In the introduction to their report, they made three general recommendations designed to minimize political friction in the exploitation of the resources of Antarctica and maximize scientific information about the conditions on the continent. They recommended that international agreements governing the marine environment be respected, that special agreements applicable to Antarctica be developed and that broad programs of scientific research be inititated to fill information gaps regarding the Antarctic.[82]

In addition to these broad guidelines, the Experts made specific recommendations regarding investigations that should be conducted prior to exploratory drilling for hydrocarbons.

78. *Id.* at vii-28.
79. SCAR Report, *supra* note 5, at 54.
80. *Id.* at 44.
81. FRAMEWORK, *supra* note 4, at vii-26.
82. *Experts' Report*, *supra* note 6, § I, paras. 1-3.

> Areas which may contain hydrocarbons are likely to be identified only after extensive basic geophysical and geological surveys. Before any exploratory drilling was undertaken there would be a need for further detailed geological and geophysical studies and the investigation of environmental factors that determine the feasibility of safe drilling operation. This second category of information should include sea-state data; weather trends during different seasons; currents; pack ice distribution, types and pressures; iceberg size, frequency, drift rate and direction; and location of contemporary icebergs scour. Information is also needed about the composition, stability and strength of seabed sediments and strata on which installations might be based.[83]

The Experts also made recommendations to be followed once a site is chosen for exploratory drilling. The seabed conditions of the proposed site should be subjected to physical studies. Special safety precautions should be designed for the equipment and methods used in drilling. Floating drilling structures must be operated in such a way that if the structure is threatened by icebergs, drilling could be interrupted rapidly and boreholes later recovered without polluting the environment. Seabed drilling installations should be used only in areas that are not subject to iceberg scour. Wherever possible, drilling installations should be built outside the area and towed to the Antarctic. Shore facilities for support should be kept to a minimum, and because of the severe climatic conditions, personnel should be intensively trained and strict codes governing operations should be developed and enforced.[84]

Since there is no existing technology that permits year-round exploitation of oil reserves in Antarctica, the next group of recommendations by the Experts focused on the design of installations that would permit year-round production. The Experts recommended that rigorous standards be set for and applied in the development of these new technologies, such as self-contained, unmanned seabed installations, in order to prevent pollution, waste and risks to human safety. Risk analyses should be performed to identify features of the environment that would pose a threat of failure or accident to the installations. Measures should then be designed to protect the installations from these environmental hazards. High standards should be adhered to in the processing of oil. Thus, associated gas should never be flared; instead, it should be reinjected or exported. Likewise, associated water should be reinjected. Storage systems should be designed to ensure that oil and

83. *Id.* para. 4.
84. *Id.* paras. 7-12.

displaced seawater are kept separated. Tankers must be built according to advanced design standards, with systems to prevent discharge of oily ballast or polluted seawater into the Antarctic seas.[85]

Finally, the Experts turned their attention to environmental hazard assessment and to remedial measures in case of accidents, recommending that assessment methods be developed to gauge the impact of hydrocarbon exploitation activities on the Antarctic ecosystem. They see these impact assessments as having two functions: (1) to assist in adjusting proposed developments in order to minimize adverse effects on the environment; and (2) to monitor any effects on the environment on a continuing basis. High priority should be given to the development of methods for the containment, recovery or safe dispersion of oil spills at sea in Antarctica, since no effective methods exist for the restoration of sea, ice or land masses damaged by spills. Also, since little is known about the impact of possible spills on the ecology of the continent, they recommended that research in this area be rapidly expanded.[86]

XIII. Economic Realities

The Group of Experts commented on the economic aspects of offshore oil activity in Antarctica as follows:

> The first action in evaluating a newly discovered oilfield is to determine its size, and where the technology for exploitation is very expensive, a field needs to be very large if it is to be worth exploiting. In the Antarctic, a further constraint would be imposed by limited access. It is difficult to envisage any Antarctic oilfield being exploited if it were only accessible to transport removing the production for 3 months of the year even though this period would suffice for the actual drilling of wells.[87]
>
> In the North Sea, using today's technology (but with year-round access), before an oilfield is exploited the potential recoverable reserves need to be of the order over 100-200 million barrels. In the Antarctic it is likely that only very large fields would be attractive for exploitation. The limit will however depend on world energy costs and on the available technology in the future. Should oilfields be found and technology allow their exploitation, it would be unwise to assume that they might not become economically attractive in the future.[88]

The Antarctic would appear to be an extremely unattractive area for offshore oil operations. Though some of our most promising areas for future development (particularly Arctic areas) have very

85. *Id.* paras. 13-17.
86. *Id.* paras. 20-23.
87. *Id.* § II, para. 25.
88. *Id.* para. 26.

hostile operating conditions, the unique combination of factors in Antarctica renders operations especially difficult and expensive.

The distances involved are enormous. Although we regularly deliver oil to ports remote from the fields of origin, and ship American-made equipment to producing areas all over the world, operating bases close to remote destinations are essential. The nearest populated areas to Antarctica are some 3,200 kilometers (2,000 miles) away in Argentine or New Zealand, though bases might be established on nearer islands. In addition, the operating season for logistic aircraft would probably not exceed six months and would be ever shorter for other than specially equipped ships.

Many factors combine to increase costs, compounding the problems of deep water, bad weather, icebergs and a short operating season. Technology and equipment will probably be more costly in the Antarctic than anywhere else due to the fact that these costs have a history of rampant escalation in frontier areas. Experience in Alaska and other northern areas has shown that personnel costs also rise rapidly in remote areas. Moreover, it is widely recognized that extremely cold weather greatly reduces personnel efficiency. The data base on many aspects of the operating environment, such as bottom characteristics and currents, is inadequate. Costly research may be required.

Assuming that a stable legal framework for offshore hydrocarbon activity existed, that acquisition costs and royalties remained at an acceptable level, and that inhibiting sovereignty disputes were eliminated, the environmental factor would remain a potentially substantial expense. Since all parties to the Antarctic Treaty are determined to protect the special environment in Antarctica, the stiff protective measures they may require could add costs disproportionate to those incurred in other areas.

The table below, prepared by an expert in the economics of offshore drilling activities, shows an estimate of the price per barrel needed to obtain a ten to fifteen percent return on investment in a hypothetical offshore area with severe climatic conditions at several different water depths. Prices are based on estimated exploration, development and production costs for a forty-well offshore producing system, excluding costs of lease bonus or other acquisition costs and excluding geological and geophysical expense. Costs have been adjusted to 1976 dollars.

	Case I 20-year field life, initial production 50,000 barrels per day, total recovery 175 million barrels.		Case II 12-year field life, initial production 30,000 barrels per day, total recovery 75 million barrels.	
Water Depth Meters	Required Price	Cost per new daily barrel	Required Price	Cost per new daily barrel
200	$ 6.60 - 8.20	$ 7,068	$13.45 - 15.40	$11,780
500	12.25 - 15.75	14,615	25.70 - 29.00	24,358
1000	20.25 - 25.55	19,874	41.40 - 48.50	40,128

Costs increase rapidly with water depth and adverse weather. Some cost comparisons are available from other areas with adverse conditions. Company estimates for the Prudhoe Bay field ran to a gross investment of about $2.4 billion for a production rate of 1 to 1.25 million barrels per day, including lease bonuses, exploration and developments costs, production equipment, and support facilities, but excluding $8 billion for the pipeline. Costs in Antarctica, estimated on a comparable basis, run to a minimum of $5 billion at 1976 cost levels, with perhaps another $6 billion needed to be expended for suitable tankers and storage. In the North Sea, investment is expected to reach around $21 billion by 1980 for a production level which will be limited by other constraints to about 2 million barrels per day. Compare, in the table above, costs per new daily barrel, estimated in 1976 dollars at $7,500 in the northern North Sea and $9,000 in Labrador.[89]

Production costs in Antarctica are not likely to be lower than those in the North Sea or the Labrador Sea. In fact, they are likely to be substantially higher. If it is assumed that the initial production capacity could be developed at a cost of between ten and fifteen thousand dollars per new daily barrel, total costs, including pipeline and storage facilities associated with the development of a one million barrel per day field in Antarctica, would range between ten and fifteen billion dollars in 1976 dollars.

Whatever scheme is devised to manage Antarctic mineral resource exploitation in an international context, revenues will undoubtedly be required for administrative expenses and to provide an economic benefit to a few or many states, selected by criteria yet to be established. One would expect that payments for the right to

89. FRAMEWORK, *supra* note 4, at vi-15 to -17.

exploit minerals in Antarctica would be set at a level which would permit profitable development. But deep seabed mining negotiations at the Law of the Sea Conference indicate that groups of states tend to respond to political rather than economic pressures. The economic burden from revenue sharing and administrative costs might well be set high enough to preclude production.

Whether Antarctic oil and gas are ultimately exploited depends upon their total costs as compared with the costs of exploiting other sources of oil and gas, and on the costs of exploiting other energy sources, whether solar, shale, coal conversion or some presently unused source or method. (A widespread use of electric automobiles, for example, might lead to a much greater use of coal as the original source of energy for transportation.)

The schedule of rising costs of petroleum is widely debated. Various projections indicate the likelihood of an oil supply-demand imbalance in the mid-1980's resulting from a considerable decline in OPEC productive capacity as compared to demand for OPEC oil. This imbalance could result in sharply higher prices.[90] A series of projections in an April 1978 report to Congress by the Energy Information Administration, indicate that the demand for OPEC oil could exceed production as early as 1981 or as late as 1989.[91] Some experts forecast that world oil prices will rise to more than double present prices in constant dollars by the late 1980's, while others argue that petroleum supplies and overall consumption patterns will remain in sufficient balance to keep rises in constant dollars at a modest level.

Synthetic fuels can be used to supplement the diminishing supply of more conventional fuels, such as oil and gas. They are especially attractive because they offer the opportunity to exploit the abundant resources of coal and oil shale. But long lead times and major investments are required for synthetic fuel production.[92] Current production from Canadian tar sands required a capital investment of about $20,000 per daily barrel of production. As a result, the selling price would have to be set well above the world market price to break even.[93] The Energy Information Administration's most optimistic projections (given strong government stimulation) are that about 800,000 barrels per day of oil equivalent from coal and shale will be produced by 1990, with assumed prices in 1977 dollars of about $13.50 per barrel for syncrude from shale and $21

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90. 2 ENERGY INFORMATION ADMINISTRATION ANN. REP. 78-79 (1977).

91. *Id.* at 79-80.

92. Nulty, *Canada Goes After the Energy in the Tar Sands*, FORTUNE, May 22, 1978, at 72.

93. *Id.* at 78..

for syncrude from coal.[94] Many problems in the production of synthetic fuel will have to be solved before they can be realistically regarded as an answer to current fuel problems.

The economic future of Antarctic mineral resource exploitation depends on a great many unknowns: future world oil prices; the costs of alternative types of energy; the nature and extent of Antarctic mineral resources; the rate and direction of technological development; the terms of the regime devised for Antarctic mineral activity; and other political, legal and enviromental constraints. Until some of these are more adequately defined, forecasts will be entirely speculative.

XIV. Conclusion

No one expects commercial drilling of offshore Antarctic oil and gas to be imminent. This is not, however, because of technological limitations. The exploration phase, even with the constraints of ice and weather, would be manageable now. The production technology now available would not be adequate to support Antarctic exploitation, but given suitable incentives, suitable technology could probably be developed.

We still know relatively little about offshore Antarctica, and these information gaps make environmental protection more difficult. Given additional information and study, it will be possible to design protective measures which could safeguard the environment against the foreseeable hazards of offshore oil and gas operations during at least several months of the year. The consequences of accidental spills could be serious, but the area affected would tend to be limited.

Whether and when Antarctic minerals will be exploited is more likely to be a function of economics than of technological development or environmental protection since it is the high cost of the last two factors rather than their lack of development that presents an obstacle. None of the distinguished members of the Group of Experts expected commercial exploratory drilling to occur before 1982 and most believed that it is not likely before 1987 or later.

The 1980's may be years of rapidly rising oil prices. The Antarctic Treaty states need to prepare for the possibility that economics and technology may bring early commercial activity to offshore Antarctica.

94. 2 Energy Information Administration Ann. Rep. 230-31 (1977).