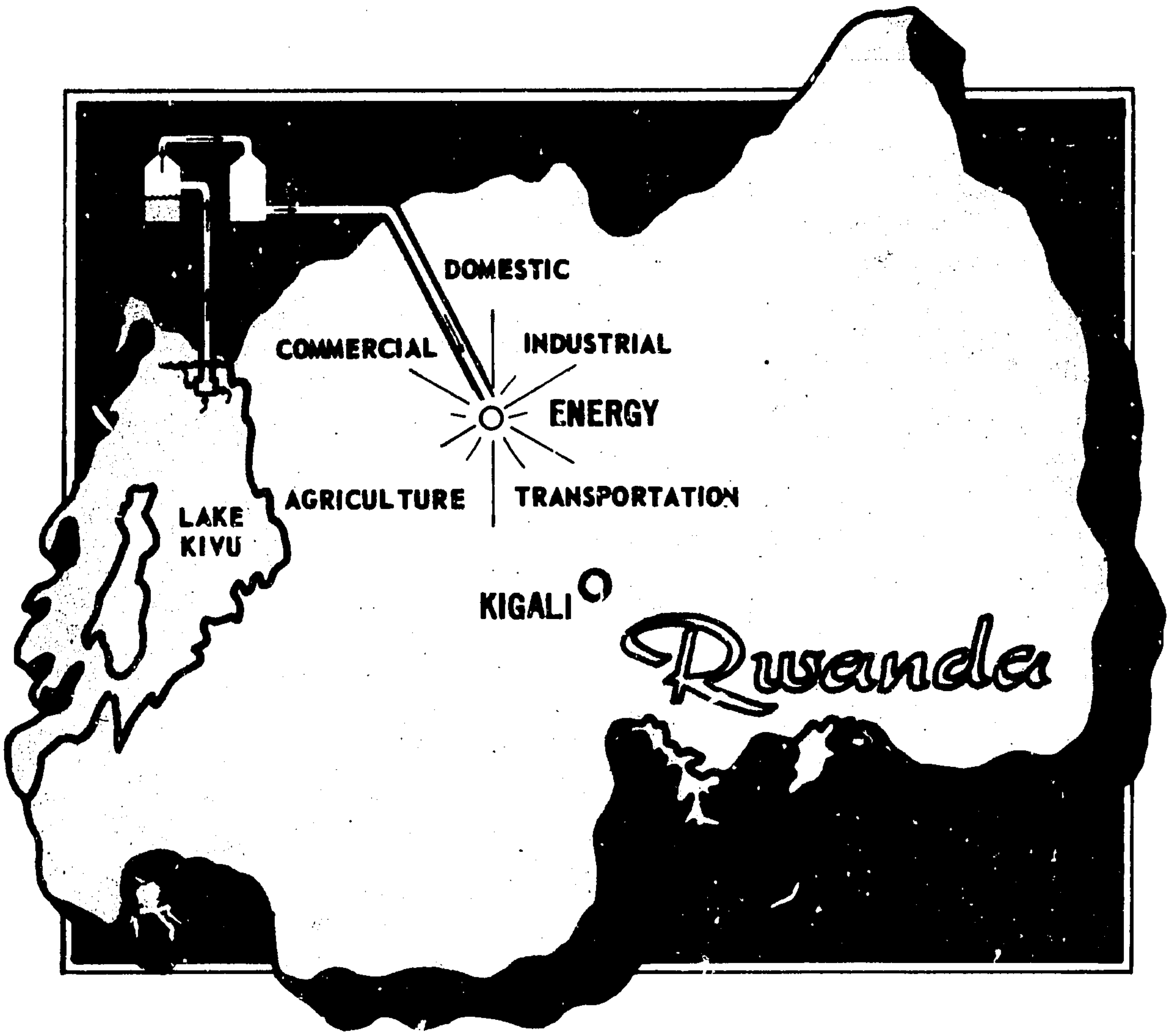
LAKE KIVU METHANE
PHASE-I INVESTIGATION



prepared for

U.S. DEPARTMENT OF STATE

AGENCY FOR INTERNATIONAL DEVELOPMENT (U.S. AID)

June 1979

WILLIAMS BROTHERS ENGINEERING COMPANY

A Resource Sciences Company

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June 29, 1979

Mr. Dalton A. Griffith
Special Assistant - Africa
Agency for International Development
United States Department of State
Washington, D. C. 20523

Dear Mr. Griffith:

We are pleased to submit our report, Lake Kivu Methane - Phase I Investigation, which completes our study activities assigned to date. Section 1, Summary and Conclusions, presents the salient points and conclusions of the investigation and can be read to obtain a brief overview of the report.

From our initial discussions, we realized the importance of investigating and assessing conclusively, if the world energy situation and the economic climate of Rwanda, coupled with the many unknown factors regarding methane reserves, exploitation and renewal, could justify a large-scale methane production operation on Lake Kivu. Not until the completion of this study did we realize the full potential of such a development.

The prospect for far-reaching benefits of a large-scale methane production program upon the economy of Rwanda is indeed exciting. Few nations have the potential of the renewable energy resource that Rwanda has in the gas reserves of Lake Kivu. Exploitation of this resource could completely reverse the current economic trend of this developing nation. Our study results demonstrate the economic viability of such a program and justifies the implementation of an intermediate-phase development program. We feel that upon reading this document, especially Section 5, Gas Utilization and Economics, you will arrive at a very similar conclusion.

WILLIAMS BROTHERS ENGINEERING COMPANY

This has been a most interesting and challenging assignment which we trust has been completed to your satisfaction. We shall look forward to answering any questions concerning the report or providing a complete review at a time convenient to you.

Yours very truly,

WILLIAMS BROTHERS ENGINEERING COMPANY

Leo F. Edison, Jr.
Project Manager

LFE:lb/3353
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REPORT

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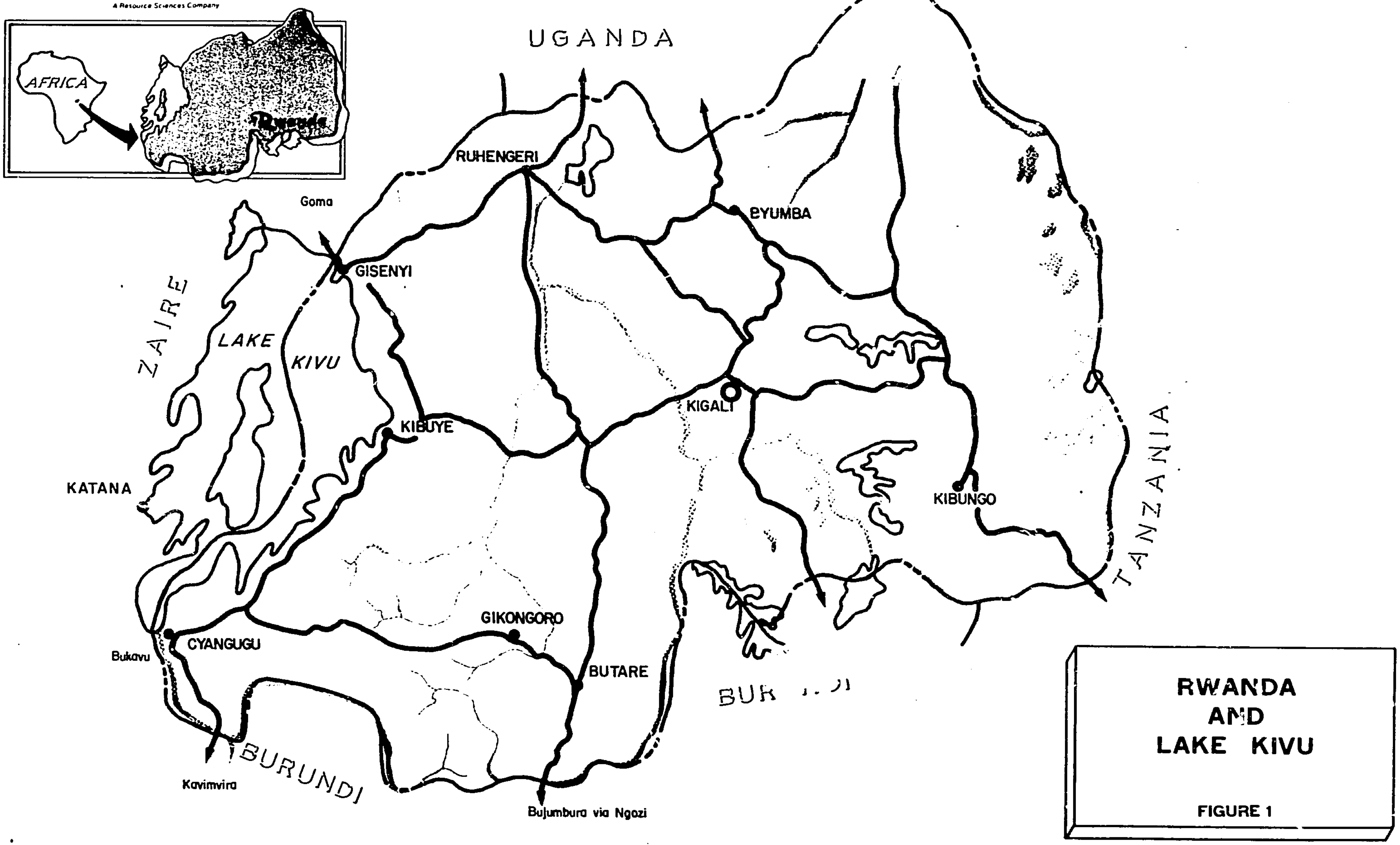


RWANDA AND LAKE KIVU

FIGURE 1

1.0 SUMMARY AND CONCLUSIONS

The United States Department of State--Agency for International Development (U.S.AID), in its program of providing technical assistance to developing countries, saw the need to address the technical, economic, financial and political aspects of methane exploitation from Lake Kivu for the Government of Rwanda.

Williams Brothers Engineering Company was selected as the engineering and management consulting firm to assist U.S.AID in the development of the project and to determine if the methane reserves in Lake Kivu could benefit the people of Rwanda.

The project was initiated with a reconnaissance trip to Rwanda and Lake Kivu, with side trips to points in the United States, Germany and Belgium to meet with the scientists and representatives of the organizations that performed earlier research on the lake. While in Rwanda and during the balance of the trip, the project team gathered information and data pertaining to the economic aspects of Rwanda, including petroleum import and use data, energy needs, industrial outlook, national debt, balance of payments, as well as many other aspects of Rwanda's economy, growth, and energy outlook in general. The project was undertaken to investigate aspects of Lake Kivu methane development in as much detail as existing data would allow, so that a program scenario for methane exploitation could be generated. The objectives of the project were met, with the results being presented in this report along with numerous supporting and parallel discussions.

Large quantities of methane were found in the deep waters of Lake Kivu in 1936. Since the discovery of methane in Lake Kivu, there have been several notable Belgian, German and American scientific missions to investigate this unique phenomenon. Estimates of methane gas in place range from 50 to 63 million normal cubic meters (1.87 to 2.35 trillion standard cubic feet). The raw gas dissolved in the lake has a composition of approximately 25 percent methane, 73.5 percent carbon dioxide, 1.5 percent inert gases and traces of hydrogen sulfide. The environment of Lake Kivu is a complex inter-relationship between physical, chemical and biological characteristics. Extensive <u>in situ</u> measurement and sampling by various scientific missions have demonstrated a high degree of stratification of the waters of the lake as they relate to salinity, temperature and density. There is a temperature inversion at approximately 160 feet (50 meters) in depth, below which the temperature increases from 37.9°F (3.3°C) to 78.6°F (25.9°C). The salinity and the gas content also increase below 160 feet (50 meters). The density variation in depth is the net effect of increasing temperature, hydrostatic pressure and gas content. The gas concentration increases abruptly between 850 and 920 feet (260 and 280 meters) in depth and is virtually constant thereafter to the bottom of the lake.

Union Chimique Belge (UCB) installed a pilot plant in 1960 to supply gas to the Heineken Brewery at the north end of Lake Kivu near Gisenyi. The plant operated almost continuously for five years (1963 to 1968) and intermittently thereafter until March, 1976. The plant produced 144 to 173 thousand cubic feet of methane per day. The plant is being refurbished by The United Nations Industrial Development Organization (UNIDO) and was scheduled to resume operations in April, 1979.

The UCB pilot plant produced gas of 72 percent methane, 16 percent carbon dioxide, 9 percent nitrogen and 3 percent oxygen with a heating value of approximately 700 Btu's per cubic foot.

In order for Rwanda to capitalize on the large methane reserves in Lake Kivu, a three-phased development program is recommended, and includes:

Phase I - Pilot Plant Phase
Phase II - Intermediate Phase
Phase III - Full-Scale Production Phase

The feasibility of producing methane from Lake Kivu has been amply demonstrated by the UCB pilot plant. However, since the capacity of the UCB plant is small, there is little measureable effect on the stratification of lake waters. Before full-scale production is initiated on Lake Kivu, it is most important to observe under dynamic conditions the various operating characteristics of the lake with significant volumes of gas being removed during an intermediate-scale production.

Three possible intermediate-scale methanol plants were examined. Methanol was selected as the final product of methane production because transporting methane gas by pipeline at relatively low rates in Rwanda would be uneconomic. The hilly and mountainous terrain in Rwanda further makes a methane gas pipeline of any major length too expensive to construct and operate. Short pipelines, however, could be used to transport methane gas to industries located near Lake Kivu and near a gas production operation. Methanol is the most versatile and clean-burning of fuels that could be derived from the Lake Kivu methane. Methanol can be used as a blend for imported gasoline and a substitute for imported fuel oil and kerosene. Further, methanol could be used for domestic lighting and cooking, thereby reducing the need for burning diminishing wood supplies. Methanol could be easily distributed by using existing trucking companies that operate in Rwanda and shipping companies that operate on Lake Kivu.

It was determined that methanol could be produced for as low as $146 per metric ton from a 95-metric-ton-per-day plant, to $194 per metric ton from a 60-metric-ton-per-day plant. This cost of methanol would be very competitive with fuels imported into Rwanda.

One of the bright spots in the future of Rwanda is this large methane reserve in Lake Kivu. Exploitation of this reserve can reduce payments that must be made for imported energy and provide energy to produce export products. At the present time, Rwanda is completely dependent on foreign nations for its petroleum products. This complete reliance on foreign oil, coupled with the fact that all land routes for petroleum importation must pass approximately 1,100 miles (1770 kilometers) through neighboring countries, places Rwanda's energy costs in constant flux and energy availability in constant question.

It has been predicted in this report that by 1985 Rwanda will be importing about 77,000 metric tons of petroleum per year at an average cost of approximately $660 per metric ton; in 1977 Rwanda imported 36,059 metric tons of petroleum at an average cost of $309 per metric ton. Even if petroleum costs were to remain at the 1977 level, the cost of methanol production from Lake Kivu would be competitive. This will not be the case, however, for rising oil prices and uncertain energy supplies experienced by the world in recent months are posing the greatest threat to the world economy since the recession of 1974 to 1975 brought on by the energy crisis of 1973 to 1974. World demand for oil is currently outstripping supply by 1.5 million barrels per day with petroleum product prices up by at least 35 percent since December, 1978. Political leaders and economists around the world fear that shortages could grow and prices might rise to damaging heights in the near-term and the long-term future. Oil product bills are rising at alarming rates along with balance-of-payments deficits in developing countries that do not produce petroleum.

Based on study estimates believed to be conservative, Rwanda will be spending about $51 million annually for petroleum imports by 1985. Intermediate-phase development of Lake Kivu methane could provide 95 metric tons of methanol per day, thereby significantly reducing petroleum imports. The monies that would stay in Rwanda because of this development would be approximately $17 million annually. With plant operating cost of approximately $5 million per year, a savings of approximately $12 million per year could be realized on a direct cash basis. With Rwanda having a $20 million deficit in 1977, a $17 million annual improvement in balance of payments would be most important to the overall economy of the country. More important yet, the cost of imported petroleum products will certainly continue to rise while the increased cost of methane development can be kept to a relatively low level; for Lake Kivu methane is a local resource, labor is local and plant maintenance would be minimal.

This study demonstrates that it would be extremely beneficial for Rwanda to develop the energy resource of Lake Kivu at the earliest opportunity. Prior to full-scale production, a plant of large enough capacity must be built and operated to allow the lake to be studied under dynamic conditions to gather operating data, determine gas reserves, methane renewal rate, and to observe the effect of gas exploitation on lake stratification and the lake environment in general. The intermediate-phase development will also provide answers as to how Rwanda and Zaire can share the gas reserves of Lake Kivu that they jointly own. If the gas from Lake Kivu can be removed at a rate effecting little or no change on gas reserves (i.e., at its renewal rate), then the question of resource allocation becomes easier for both countries.

Besides providing for the building of a plant that will immediately help the economy of Rwanda, the intermediate-phase program will assess the feasibility of full-scale gas removal from Lake Kivu, a vital concern to the long-term use of the gas resource of the lake. In order for Rwanda to develop the energy resource of Lake Kivu in a timely manner, the finance and planning stage of the intermediate-phase development program should begin immediately. The following scope of work for the finance and planning stage is recommended.

- <u>Project Management</u> - Effective project management is the key to quality project performance. The project management responsibility should be assigned at an early stage to a firm with a multi-disciplinary world-wide operating capability.

- <u>Market Identification</u> - Potential purchasers and users of energy from Lake Kivu need to be identified. Conditional commitments and contracts should be obtained to support project financing.

- <u>Transportation Evaluation</u> - Potential common carriers to distribute methanol should be identified. Potential common carrier arrangements should be evaluated to determine the optimum means of transportation of the product from Lake Kivu to the user.

- <u>Preliminary Plant Design</u> - A preliminary design of the intermediate-scale plant must be developed to prove technical feasibility and to provide a basis to estimate cost of construction. This design stage will include site selection and coordination of design with the environmental study which will be needed.

- <u>Environmental Study</u> - An environmental study must be performed during the intermediate-scale design and operation. The data obtained by the environmental study will aid in making various design choices to help protect the environmental, physical and biological integrity of the lake.

- <u>Estimate Plant Costs</u> - Definitive estimates of the capital and operating costs need to be made to support project financing.

- <u>Preparation of Financial Report</u> - A detailed report showing the data, information and results obtained from the completion of the above-described scope of work should be made and presented in sufficient form and character to support project financing.

- Determination of Financial Resources - A complete investigation should be made of all financial resources, both public and private, that might be utilized to finance the project. Detailed presentations should be made to various individuals and groups illustrating the merit and feasibility of the project so that necessary financing can be obtained.

- Project Implementation - After project financing is obtained, the project should be implemented at the earliest opportunity. Project implementation will include final design, construction and plant startup.

An engineering company with a world-wide multidisciplinary operating capability should be utilized to provide management and engineering services to the government of Rwanda and others who might sponsor this project.

2.0 INTRODUCTION

In 1936 it was discovered that large quantities of methane gas were dissolved in the deep waters of Lake Kivu, an east-central African lake. The lake lies between Zaire to the west and Rwanda on the east and is about 100 miles (160 km) to the north of Lake Tanganyika (Figure 1). It is situated at the highest point of the east African rift valley approximately 4790 feet (1460 meters) above sea level. Lake Kivu has a surface area of about 925 square miles (2400 square kilometers) and a maximum depth of almost 1640 feet (500 meters). Since the discovery of methane, there have been several scientific investigations into the chemistry, geology, hydrobiology and numerous other aspects of this most unusual lake.

As part of its international development program, the United States Department of State--Agency for International Development (U.S.AID) engaged Williams Brothers Engineering Company to assist in a study to ascertain how the development of methane reserves in Lake Kivu could benefit the people of Rwanda. Rwanda is a very small, highly populated African nation, has no known natural petroleum reserves, and is completely dependent on foreign sources for its petroleum needs. Because it lacks its own reserves, it must import all petroleum products, which contributes greatly to its negative balance of payments and increased national debt. U.S.AID saw that a possibility exists for Rwanda to alter its energy picture, reduce its national debt, and stimulate industrial and economic growth by developing the energy resources available in the methane reserves of Lake Kivu.

Williams Brothers Engineering Company and U.S.AID, in coordination with and with full cooperation of the Rwandan government, undertook to address the technical, economic, financial and political aspects of methane exploitation, and to develop a preliminary intermediate-phase development program scenario. The study was initiated with a reconnaissance trip to Rwanda and Lake Kivu. The investigation team visited the United States, Germany and Belgium to meet with the scientists and representatives of the organizations that performed much of the earlier research on the lake to discuss details of that research and obtain pertinent literature. While in Rwanda, the team gathered information and data pertaining to the economic aspects of the nation, including petroleum import and use data, energy needs, industrial outlook, national debt, balance of payments as well as many other aspects of the nation's economy, growth, and energy outlook.

2.1 Study Objectives

This study was undertaken to investigate Lake Kivu methane development in as much detail as existing data would allow and to develop a program scenario for methane exploitation. The objectives of the study were numerous and included the following:

- Identify, examine and synthesize existing literature on Lake Kivu, its gas reserves and the national economics of Rwanda.

- Ascertain the quantity and quality of methane reserves, source, and renewal rate.

- Identify discrepancies or gaps in the available data, determine what additional studies might be needed to adequately assess the unknowns and answer important questions which as yet remain unanswered.

- Identify the numerous physical, chemical and biological factors that must figure in any equation for methane exploitation.

- Assess the possibility of inadvertent loss of gas reserves by a natural lake overturn or as a result of methane removal.

- Develop various technical scenarios for methane exploitation, and identify what appears to be the most desirable process.

- Provide a detailed estimation of project economic viability.

- Identify options and develop cost estimates for the distribution of this energy resource throughout the country.

- Compare the costs of methane development and product economics with the costs of alternative fuels presently imported.

- Project future methane exploitation economics with petroleum distillate import economics, and address the matter of the relationship among methane development, petroleum imports, national economics/ debt and balance of payments.

- Discuss the problems influencing exploitation of the resource, which would include ownership and lake commission involvement and the regional aspects of exploitation of the resource.

- Identify and analyze the anticipated environmental impact of exploitation and the means of addressing environmental problems.

- Prepare a preliminary program scenario for methane exploitation.

- Identify and examine potential domestic, industrial, and commercial uses for methane in Rwanda and neighboring countries.

These objectives were met, and the study results are presented in this report, along with numerous supporting and parallel discussions. It should be mentioned that, although this report represents much of the latest information available, it should not be thought to represent an all-inclusive, state-of-the-art methane development document. Obviously, the report could have included additional data and material as well as in-depth (computer) analysis of many of the resource and economic aspects of the project if time and money had not been a constraint.

2.2 Report Format

This document is organized in such a manner that the reader can easily access those areas of greatest interest. The study results are reported in the following four major sections.

Section 3.0 Lake Kivu--Its Gas Reserves and Environment, which discusses the physical, chemical and biological aspects of Lake Kivu, describes the source of the methane reserves, and identifies the interrelationships between the physical and biological aspects of resource renewal;

Section 4.0 Phased Gas Production Plan, which presents the various methane exploitation scenario options and discusses the economic and technical aspects of each alternative;

Section 5.0 Gas Utilization Economics, which identifies the economic aspects of methane exploitation and what effect it could have on Rwandan economics; and

Section 6.0 Intermediate-Phase Development Finance and Planning, which outlines a recommended financial and planning study to initiate the intermediate-phase development program for exploitation of the Lake Kivu methane reserves.

To develop a complete picture of the methane reserves, exploitation of this resource and the possible effect on the Rwandan nation, the complete report should be reviewed.

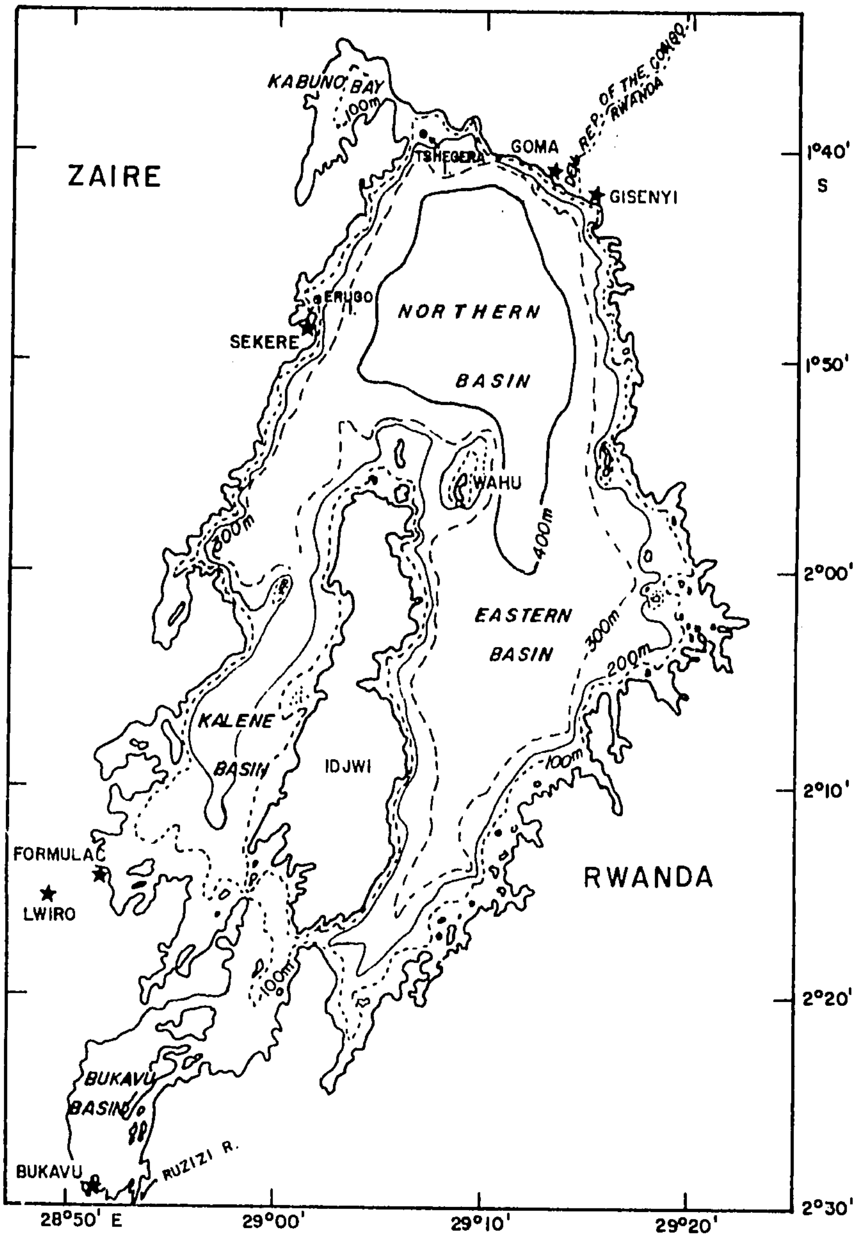
3.0 LAKE KIVU -- ITS GAS RESERVES AND ENVIRONMENT

Lake Kivu is the highest (4790 feet, 1460 meters above sea level) of several lakes in the rift valley of east-central Africa. Its surface area, excluding the islands, is about 925 square miles (2400 square kilometers) and has a maximum depth of almost 1640 feet (500 meters). The lake is divided into several basins, with the northern basin being the largest and deepest. Its total water volume is about 140 cubic miles (580 cubic kilometers). The lake waters discharge into the Ruzizi River to the south at an estimated rate of 0.77 cubic miles (3.2 cubic kilometers) per year (Figure 3-1).

About 1650 feet (500 meters) of sediments underlie the lake, and these overlie a basement believed to be crystalline rock of Precambrian age. The lake is surrounded by volcanic and geothermal activity, and, as recently as January, 1977, there was a violent volcanic eruption at Nyiragongo near Gisenyi.

3.1 Gas Reserves -- Volume and Composition

The existence of large amounts of methane dissolved in the deeper waters of Lake Kivu below 820 feet (250 meters) is a unique phenomenon. The gas is held in solution because of the hydrostatic pressure (e.g., at 980 feet, 300 meters this amounts to about 440 pounds per square inch or about 30 atmospheres). The bulk of the gas is contained in the northern basin the subsidiary basins are too shallow, and their gas content is, therefore, insignificant. The gas was first discovered in 1936, and since then there have been several Belgian, American and German scientific missions, notably by:



SOURCE: E. T. DEGENS ET AL. (REF. 1)

Figure 3-1 Bathymetry of Lake Kivu

a) Institut Royal des Sciences Naturelles, Brussels, Belgium from 1949 to 1959.
b) Union Chimique Belge (UCB), Brussels, Belgium, in 1953 to 54.
c) Woods Hole Oceanographic Institution (WHOI), Woods Hole, Massachusetts, in 1971 to 72.
d) Bundesanstalt fur Geowissenschaften und Rohstoffe (BGR), Hannover, Germany, in 1974 to 75.

Estimates of the methane gas in place range from 1.87 to 2.35 trillion standard cubic feet or 50 to 63 billion normal cubic meters, a standard cubic foot being measured at one atmosphere and 60°F (15.5°C) and a normal cubic meter being measured at one atmosphere and 32°F (0°C).

	Gas in Place	
	Trillion Standard Cubic Feet	Billion Normal Cubic Meters
WHOI (U.S.A)	1.87	50
UCB (Belgium)	2.13	57
BGR (Germany)	2.35	63

The average raw gas-water ratio is 1.62 to 1, with methane comprising approximately 24 percent of the raw gas, thus, any methane recovery scheme would require handling a very large amount of water.

UCB shows the raw gas dissolved in Lake Kivu has the following approximate composition:

	Percentage by Volume
Methane, CH_4	24.90
Carbon dioxide, CO_2	73.50
Hydrogen sulfide, H_2S	0.05
Inert gases (mainly N_2)	1.55
	100.00

The Union Chimique Belge process used in the pilot plant at Cap Rubona near Gisenyi produced gas of approximately the following composition:

	Percentage by Volume
Methane, CH_4	72
Carbon dioxide, CO_2	16
Nitrogen, N_2	9
Oxygen, O_2	3
	100

This gas has an approximate heating value of 697 Btu's per standard cubic foot (6195 kilocalories per normal cubic meter).

3.2 Environment - Physical, Chemical and Biological

The environment of Lake Kivu is the result of complex interrelationships between the physical, chemical and biological characteristics of the system. Within each of these general parameters are found very atypical, or at least unique, aspects that, when considered together, represent a most unusual physical and biological ecosystem. The major atypical characteristics include the inverted temperature profile, salinity stratification, gas content and bacterial flora. This unusual and complex system necessitates a thorough understanding of its numerous peculiarities if it is to be dealt with in a sound, professional manner. This section identifies and discusses many of the important environmental questions that must be addressed relative to the removal of large quantities of gas from the lake.

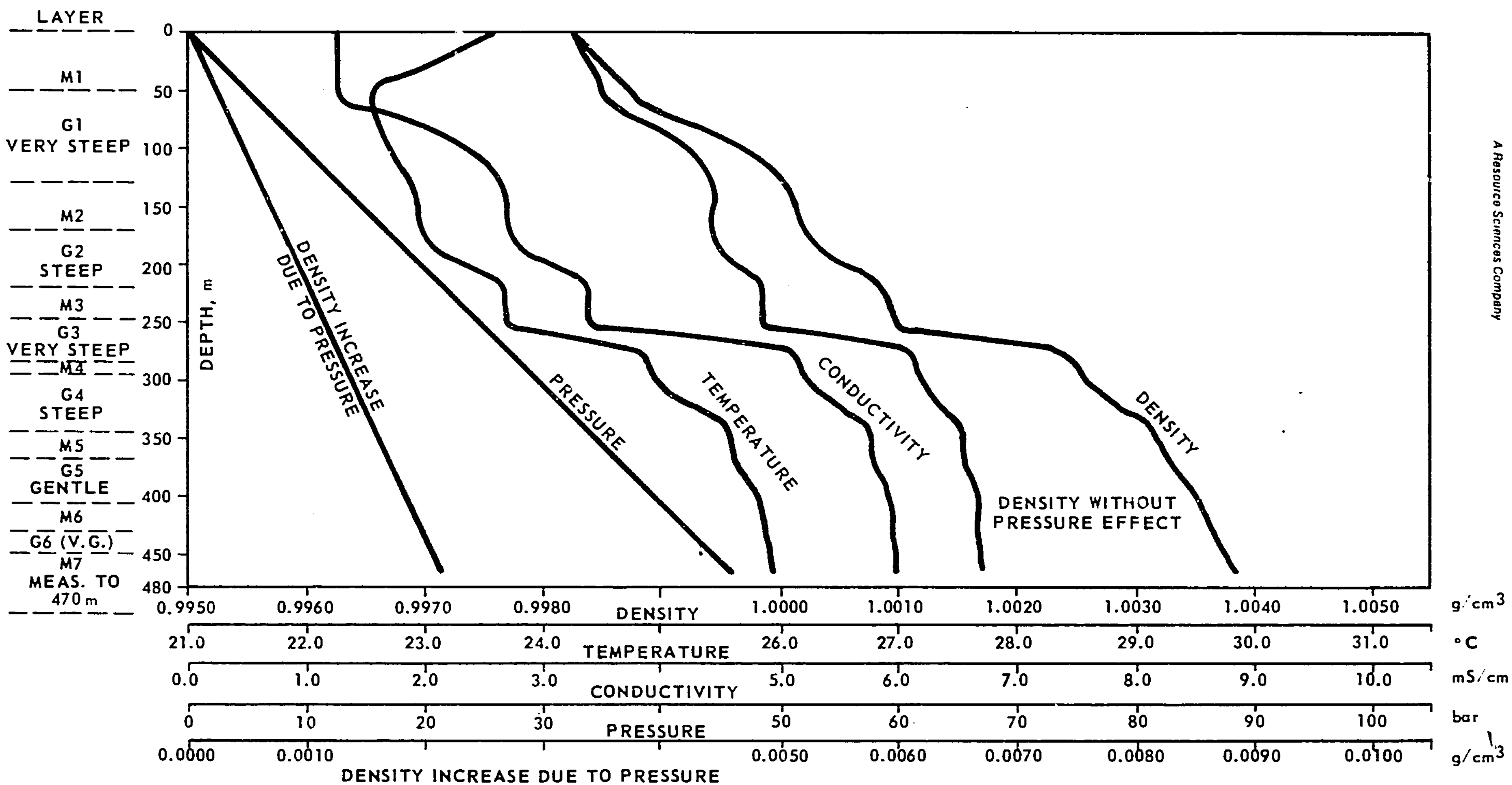
3.2.1 Lake Stratification and Overturn

Lake Kivu demonstrates unusual and complex stratification mechanics. One most unusual characteristic is the temperature profile. Generally speaking, the surface water (epilimnion) of most lakes is warmer than the bottom water (hypolimnion), and a thermocline of rapidly changing water temperature divides the two layers. The density difference between the two layers (brought about by temperature) and associated thermocline creates a stratified situation which prevents circulation between layers until the temperature regime is modified. Lake Kivu does not possess this typical temperature stratification; its hypolimnion is warmer than its epilimnion. In addition, the lake does not possess the temperature-related thermocline, but rather a chemocline, which is an area of rapidly changing chemical character.

The salinity character of Lake Kivu is predominantly responsible for the density stratification, whereas in most lakes stratification is a function of temperature. The high salinity of deeper Kivu waters allows warmer water to remain below cooler water, for the warmer water is heavier (denser) than the cooler, less saline water above. The unusual temperature and salinity characteristics of Lake Kivu are a result of its active geophysical/geochemical history. Hydrothermal activity discharges warm, saline water into the bottom of the lake, which, because of its density, spreads laterally instead of rising as would be expected for warmer water. Hydrothermal discharges, volcanic activity and local geology contribute to the warm, highly saline waters of the lake.

Extensive in situ measurements and sampling have demonstrated a high degree of stratification of the lake waters regarding salinity, temperature and density. Laterally, these parameters are fairly uniform. According to BGR, which has carried out the most extensive surveys using a submarine probe, the water column of the main basin may be divided into seven mixed layers of practically uniform properties, interposed among six "gradient" layers showing gradational property variation (Figure 3-2). The steepest change occurs over the interval of 814 to 928 feet (248 to 283 meters) of gradient layer three.

There is a temperature inversion at about 165 feet (50 meters), below which the temperature increases from 72.7°F to 78.6°F (22.6°C to 25.9°C). The salinity (and thus conductivity) and the gas content also increase below 165 feet (50 meters). The density variation is the net effect of increasing temperature, hydrostatic pressure and gas content. Density increases by 0.0034 gram per cubic centimeter, or by a total of 0.0055 gram per cubic centimeter including the pressure effect. The gas (both methane and total gas) concentration increases abruptly between 853 and 919 feet (260 and 280 meters), gradually from 919 to 1280 feet (280 to 390 meters) and is virtually constant thereafter (Figure 3-3).

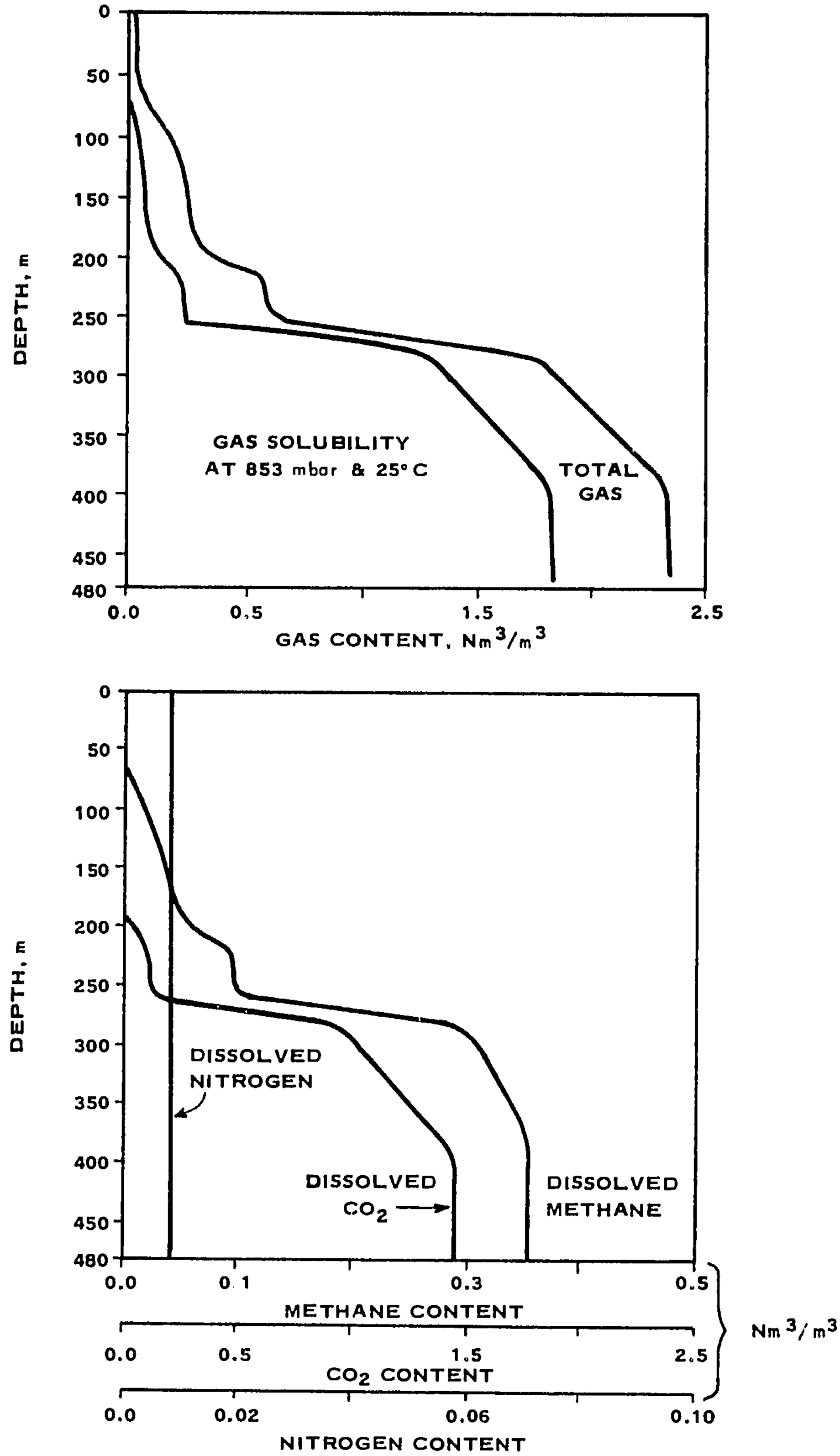


SOURCE: K. TIETZE (REF. 6)

LEGEND: M = MIXED LAYER
G = GRADIENT LAYER

NOTE: MEASUREMENTS BY BGR – NOV. 14, 1974 TO JAN. 28, 1975

Figure 3-2 Average Vertical Profiles of Physical Measurements in Principal Basin



SOURCE: K. TIETZE (REF. 6)

Figure 3-3 Dissolved Gas Profiles in Principal Basin

The removal of gas from the lake will necessitate the transportation of water from the deep portions of the lake to the surface and, after processing, back to the lake. What effect this will have on the stability of the lake and whether or not it could induce partial lake overturn are questions which must be addressed. There are no records that indicate that the lake has undergone a complete overturn. If complete overturn were to occur, the gas reserves in the lake would be lost; and it would take an unknown number of years to restore present-day quantities of methane. The history and character of the lake indicate that it is very stable in its present state, and there is no reason to believe that an overturn is likely or even remotely possible. Over the past 100 years, major meteorological and geological events have occurred without disrupting lake stability or causing even a partial overturn, demonstrating the highly stable nature of lake stratification. Evidence indicates that the lake will continue to maintain its internal integrity and that the methane is a renewable resource that can be tapped and utilized. The recommendations for study relative to gas removal outlined in Section 4.0 should be undertaken to document and satisfy questions concerning lake overturn, as well as the numerous other production and environmental questions.

3.2.2 Volcanoes and Earthquakes

Lake Kivu is located in the east-central African rift valley characterized by volcanic and geophysical activity. Historical geological occurrences have brought about major changes in the lake and have allowed it to develop its most unusual stratification and chemical character. This activity is present today; for as recently as January, 1977, there was a violent volcanic eruption at Nyiragongo near Gisenyi.

Earlier eruptions occurred in 1948 with lava flows reaching the lake shore, and in May of 1971 with flows solidifying just before reaching the lake. Cores taken from the lake bottom show numerous layers of volcanic ash and tuff beds, some of which are probably the result of eruptions of sub-lacustrine cones. Geophysical studies imply numerous stages of geologic activity of the underlying deeper mantle. Lake Kivu is probably in a transition between volcanic/hydro-thermal activity and sea-floor spreading. One must remember that geologic time is expressed in thousands and millions of years.

3.2.3 Gas Origin

There are a number of possibilities for the origin of the methane in Lake Kivu. A single process is probably responsible for the majority of the reserve; however, it is likely that two or more are working in concert.

Methane producing mechanisms include the following:

a) Decomposition of plants, as in marshes
b) Hydrothermal activity related to volcanic emanations
c) Seepage from a petroleum reservoir
d) Bacterial action on volcanic emanations
e) Bacterial action on organic substances in the lake and lake sediments
f) Thermocatalysis

A volcanic origin is excluded since methane has not been detected in the volcanic emanations and hot springs around the lake, and because traces of higher hydrocarbons are also present in the lake gas. These heavier hydrocarbons are not found in volcanic gases, which are comprised principally of CO_2 with minor amounts of hydrogen. A petroleum origin is unlikely (though cannot be totally excluded) since the very low concentrations of higher hydrocarbons--particularly ethane--are not typical of natural gas compositions. BGR shows the methane/ethane concentration ratio to be more than 1000 to 1. WHOI and BGR show the following composition for a sample taken from a depth of 985 feet (300 meters); the results are expressed in weight ratios relative to ethane.

	WHOI	BGR
Methane	650	1280
Ethane	1	1
Propane	0.33	0.14
iso - Butane	0.07	0.04
n - Butane	0.04	0.04
$C_5 + C_6$	0.61	

Woods Hole Oceanographic Institute (WHOI) investigations have indicated that the principal part of the methane may be due to the action of bacteria on CO_2 and hydrogen supplied by volcanic emanations into the deep water. The deep parts of the lake do contain a rich fauna of methane-producing bacteria.

Carbon isotope analysis indicates that only a small part of the methane could have originated from the decomposition of plankton.

WHOI attributes the presence of C_2 to C_4 hydrocarbons to microbial (bacterial) processes in the lake sediments and the traces of C_5 and C_6 to thermal decomposition of older sediments.

Figure 3-4 is a BGR diagram showing the various possible mechanisms of methane formation. BGR concluded from its isotope and other analyses that the dominant mechanism is bacterial activity on the organic substance of the sediment. Other evidence demonstrates that the methane is produced by the activities of bacteria on abiotic CO_2 derived from volcanic emanations. It is most probable that both actions are taking place. For a more detailed discussion of the bacterial mechanism, please refer to Section 3.2.4.1.

Although the origin of the methane may be more of a scientific interest, its practical importance lies in whether or not the gas resource is renewable over a reasonably short period of time. The lake appears to be in a state of equilibrium; the gases being lost in the biozone are replenished in the deep waters at about the same rate. This conclusion is based on the good agreement between two sets of methane and CO_2 content data taken 20 years apart by Schmitz and Kufferath in 1955, and by Tietze (BGR) in 1974 to 75. However, the methane concentration data collected by WHOI in 1973 are higher.

3.2.4 Biological Resources

Degasifying deep Lake Kivu waters by transporting the water to the surface and ultimately returning it to the lake will have some effect on the aquatic flora and fauna. Section 4.2.1 identifies a number of studies that are recommended for the intermediate production phase to answer important questions relative to the net impact on aquatic organisms. The organisms in Lake Kivu have evolved in parallel with the evolution of the lake. The organisms have adapted successfully to the present environment, and will

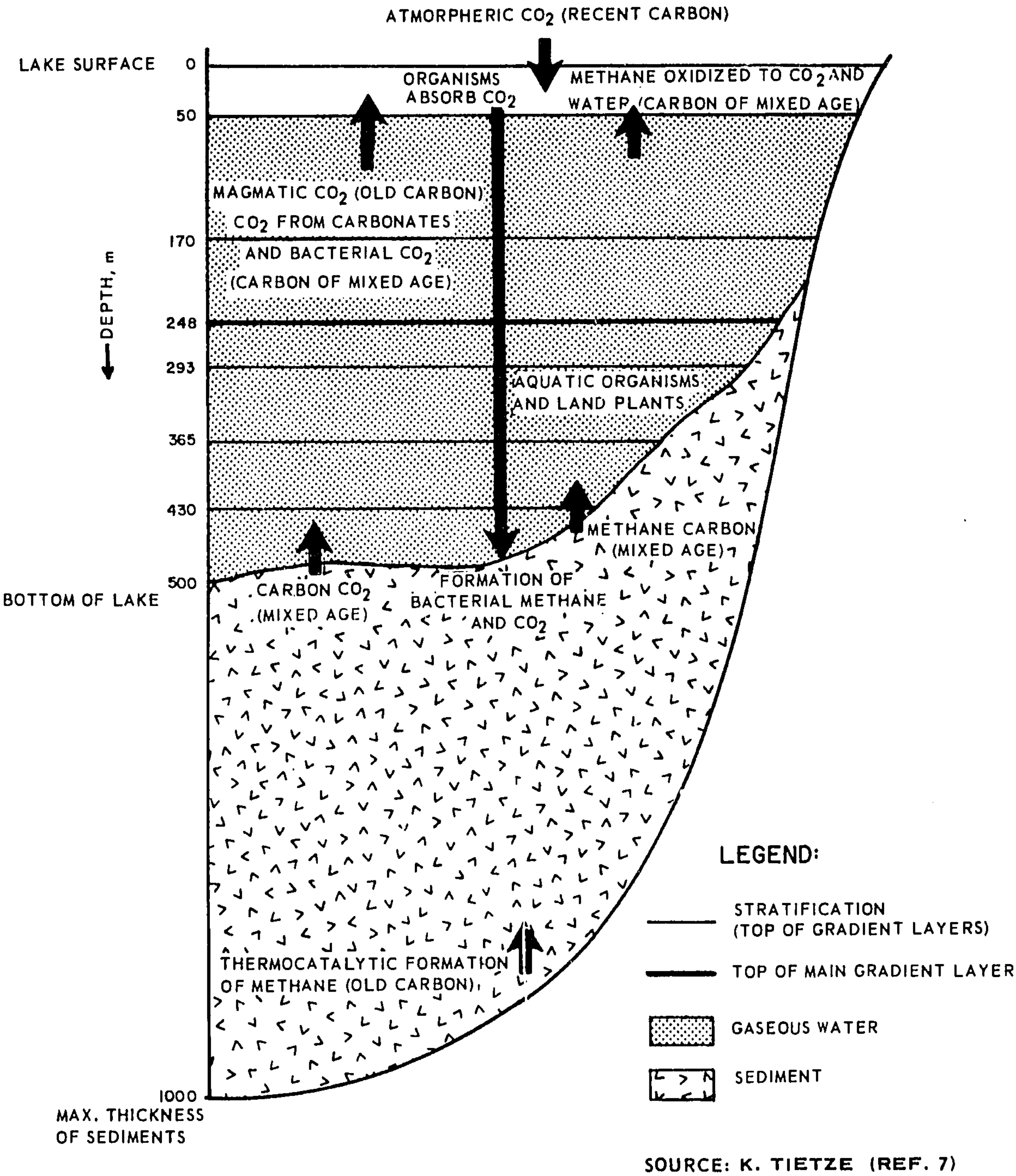


Figure 3-4 Possible Mechanisms of Methane Formation in Lake Kivu

continue to change as conditions in the lake are altered by natural processes. The trend in Lake Kivu seems to be in the direction of higher salinities. As the salinity increases and the conditions become more severe, organisms are less able to adapt; and, therefore, the number of kinds of organisms in the lake can be expected to decrease. Again, one should be reminded that, when referring to changing conditions in the lake and organism evolution, we are talking about a relatively long time frame (hundreds of years). The lake has had a very dynamic geophysical past and is presently very active. The effects that this activity is having on the aquatic biota, the changes that organisms must make to keep up with the changing environment/habitat, and the impact of removing gas from the lake are questions which require further research. These questions are important when considering the overall productivity of the lake relative to gas, protein reserves, and important species.

3.2.4.1 Bacteria

Relative to the methane reserves in Lake Kivu, the bacterial flora represent probably the most important organism in the system. It has been shown that the bacteria are responsible for most, if not all, of the methane in the lake. These bacteria are quite unique, and are of basically two types: chemotrophic bacteria (those that use chemical energy), and phototrophic bacteria (those that utilize solar energy). The chemotrophic bacteria are the important methane producers. These bacteria can be divided into two groups, chemolithotrophic bacteria (those that use chemical energy derived from the oxidation of inorganic compounds such as NH_3, H_2S and H_2) and chemoorganotrophic bacteria (those that use chemical energy from the oxidation or fermentation of organic compounds).

The chemolithotrophic bacteria, those bacteria that are capable of utilizing chemical energy derived from H_2, are the individuals responsible for most of the methane reserves found in Lake Kivu. These organisms produce methane by carrying out the reaction:

$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O \quad \text{(anaerobic respiration of } CO_2\text{)}.$$

It should be mentioned here that evidence indicates that chemoorganotrophic bacteria, as well as a thermocatalytic process taking place in the sediment at the bottom of the lake, may also be responsible for a portion of the methane. Certainly, methane is being produced from organic compounds; however, evidence has demonstrated that the levels of biogenic (organic) carbon in the lake are not large enough to account for the quantities needed to produce the reserves of methane found in the lake. Likewise, it has been shown that the extremely large reserves of carbon in the form of CO_2 in the lake are of abiogenic origin (inorganic--not produced as a result of biological processes) produced from magmatic/volcanic activity. This combination of information greatly supports the theory of chemolithotrophic production of methane.

Because the methane is biologically produced in the lake, it represents a renewable resource. Evidence indicates that the methane reserves in the lake are probably at or near equilibrium; that is, the present production of methane equals the amount being lost by diffusion and consequent decomposition by bacteria ($CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$). Essentially, if the reserves were to remain untapped, there would be little further accumulation of methane. Since the methane is a renewable resource, it could be tapped (removed) with a continual supply being produced by the bacteria, as opposed to oil or natural gas taken from the ground reserves that, once depleted, can never be renewed.

Maximum effort must be expended in protecting the source of the methane (bacteria). To remove the methane from the deep water, the water must be brought to the surface. With the water, quantities of bacteria will be transported to the surface, during which a pressure change of about 30 atmospheres will take place. In addition, the bacteria will experience abrasion and physical manipulation during the transportation and gas removal processes. If the degasified water is discharged at or near the surface, a given quantity of bacteria will be taken out of methane production but replaced by natural reproduction at an unknown rate. If the water is returned to the same level from which it was removed, the bacteria that survive the trip to the surface and back will be returned to production.

The process of degasification will have its effect on the level of methane-producing bacteria. How it will affect yield cannot be determined at this time and will depend on quantity of water degasified and mortality rate of bacteria involved as well as discharge point of the degasified water. These questions should be answered and are addressed in Section 4.2.1.4.

There is every reason to believe the methane resources in Lake Kivu can be tapped and utilized on a large scale with little negative impact on the lake biology and total gas reserves. A carefully designed intermediate-scale production project would determine if this is indeed true.

3.2.4.2 Fish

The chemical character of Lake Kivu has limited the number of fish species common in the lake. The exact number of species and their commercial value and the potential of the lake's fishery apparently have not been adequately established by recent investigations. It has been reported that eleven to twenty species of fish are present in the lake and that Lake Kivu contributes only 15 percent of the fish caught in Rwanda. As indicated in Section 4.2.1.4, investigations into the resident species (quality and quantity) should be carried out as well as investigations into the potential of the commercial fishery.

The fish of Lake Kivu have adapted to high salinity water. The primary and secondary productivity (phytoplankton-algae and zooplankton-animals, respectively) in the lake is high due to the available nutrients; and there is no reason to believe that productivity in the highest trophic level in the lake (fish) is not also high. Although the salinity of surface waters is relatively high when compared to water of a typical fresh water lake, it does not mean that the salinity is high when considering the resident fish and other organisms in the ecosystem. The aquatic life has evolved in the system and will continue to do so; and it is not at all logical to assert, as is stated in one study, that fish populations in the lake are impoverished merely because the lake has fewer numbers of fish species than a "typical" lake. One does not ordinarily compare fish species in a marine ecosystem with those in a fresh water lake; the same holds true with comparing a fresh water lake with a saline lake such as Lake Kivu.

The approximate concentration of salts in the surface waters of Lake Kivu are as follows: Ca--4.8, K--97.4, Na--121.6, Cl--55, SO_4--23.8 gram-atoms per liter. These levels increase greatly below the 165 foot (50 meters) chemocline but have no real influence on the fishes, for the latter do not venture to those depths. The levels of salts shown above do not represent a limiting factor or stress factor for the majority of the fish in the lake and most probably are of little or no significance. Furthermore, resident fish may very well need these levels to thrive as do fish in marine environments. The level of salts in the lake should not then cause one to believe that the fishery must be of no consequence to the protein needs of the country. One factor which must also be remembered is that the unique chemical character of the lake most probably has associated with it high levels of trace elements which would be concentrated in fish flesh. Fish taken from the lake and consumed certainly represent a very important source of these essential elements.

In addition to the salts listed above, other elements and compounds are important to consider, including: N (as NH_4)--18 P--0.8, Si--231, N (as NO_3 + NO_2)--1.9 and N (as urea)--0.4 gram-atoms per liter. None of these elements or compounds in the surface waters are at levels which approach a critical point for most fish or other aquatic organisms. The radical of greatest significance would be NH_4 (ammonium), for high levels can become toxic to aquatic life. The present level of NH_4 in surface waters of 18 gram-atoms per liter represents aproximately 0.32 part per million and is not at a significantly high level. The real potential for NH_4 toxicity would come from the release of bottom waters at the surface. Water at 1445 feet (440 meters) contains approximately 7105 gram-atoms per liter, which corresponds to about 128 parts per million. At this level, NH_4 would be toxic to most of the resident fishes as well as much of the other flora and fauna found in the surface waters. In addition to the NH_4, large quantities of highly saline waters would be discharged. If discharged at the surface or near surface, the water would tend to sink because of its high density. The salinity of the water would in itself have a negative impact on the fishes, the severity of which would depend on the extent and location of the area affected. An even greater potential negative impact would be the possibility of disrupting the stratification of the lake. If this sinking column of water were to precipitate a turnover, the methane resources in the lake could be lost or threatened, and large quantities of highly saline and possibly toxic waters would be mixed with surface water, resulting in significant biological mortality.

The final disposition of degasified water represents a potential impact on the resident fish and other aquatic life in Lake Kivu. The ecosystem that presently exists represents no serious limitation to the fish populations; however, surface discharge of high-salinity bottom waters could have a serious impact on aquatic life.

3.2.4.3 Plankton

The populations of phytoplankton and zooplankton in the surface waters of the lake are very rich. This richness is reflected in total numbers and not species numbers. Essentially there exists only a relatively few types of organisms, but the number of individuals of each type (species) is very high. This characteristic is typical of mature or aging aquatic ecosystems. The process of eutrophication (aging) in Lake Kivu has been accelerated by the atypical historical geological activity. Lake Kivu has undergone an extremely dynamic development with volcanoes and earthquakes common to its early years. This development has brought about unusual temperature and salinity characteristics, which in turn have dictated the character of the lake's biology. As conditions become more severe, species must either adapt to the change or they cannot survive. As this evolution takes place, many organisms are eliminated from the ecosystem, leaving behind those that have adapted to the changing character of the ecosystem. This natural evolutionary process brings about significant changes in species diversity. Because many species have been eliminated, those that remain have far fewer competitors and are, therefore, able to take the greatest advantage of their environment/habitat. This generally results in very high numbers of individuals of those species that have evolved and adapted to the new ecosystem. This is essentially the case in Lake Kivu. The unusual temperature and salinity characteristics have eliminated many species, and those that remain thrive.

Primary productivity in the lake is responsible for the health of the surface waters of the lake, which is responsible for the production of the highest trophic (feeding) levels in the system (fish). It has been shown that about 90 percent of the organic material/nutrients produced in the surface waters are continually recycled there. Primary productivity has been estimated at approximately 1.5 grams per square meter per day; and, of that, the vast majority is metabolized or oxidized in the surface waters. The remaining (10 percent) sinks and becomes available to organisms in the deeper areas of the lake.

4.0 PHASED GAS PRODUCTION PLAN

In order for Rwanda to capitalize on the large methane reserves in Lake Kivu, a phased development program should be utilized. After examining and reviewing the information and data concerning Lake Kivu, a three phase program is recommended.

Phase I - Pilot Plant Phase
Phase II - Intermediate Phase
Phase III - Full-Scale Production Phase

4.1 Pilot Plant Phase

Union Chimique Belge installed a pilot plant in 1960 to 1962 at Cap Rubona at the north tip of Lake Kivu near Gisenyi to supply gas to the Heineken Brewery. The plant operated almost continuously for five years (1963 to 1968) and intermittently thereafter until March, 1976, with a throughput of 144 to 173 thousand cubic feet of gas per day (3860 to 4630 normal cubic meters per day). The plant is being refurbished by the United Nations Industrial Development Organization and was scheduled to resume operation in April, 1979.

A schematic diagram of the pilot plant process is shown in Figure 4-1. The system for collection of the raw lake gas consists of two reinforced polyurethane pipelines, each 2800 feet (850 meters) long and of 12 inches (300 millimeters) internal diameter (ID), each collecting water from a depth of about 980 feet (300 meters). Water flow into the pipelines is initiated by air lift, using an air compressor. As the dissolved gas comes out of solution due to the lessening of pressure, natural gas lift takes over (after about

WILLIAMS BROTHERS ENGINEERING COMPANY
A Resource Sciences Company

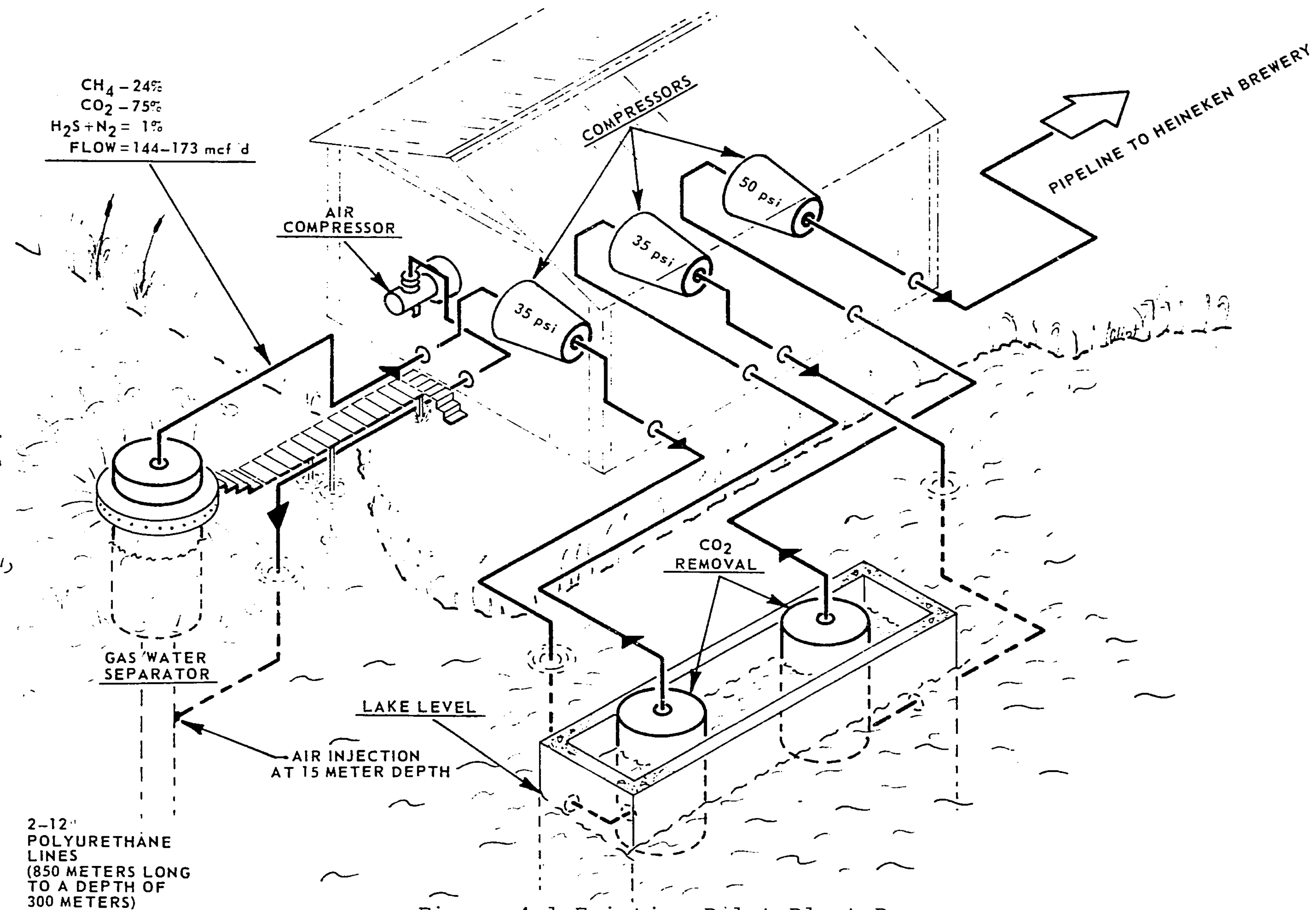


Figure 4-1 Existing Pilot Plant Process

30 minutes), delivering the water into a gas-water separator at the lake surface. This automatic gas lift (UCB autopompage principle) brings water to the surface, is self-sustaining and requires no pumping, resulting in a very energy-efficient water transport system.

The gas leaving the separator is compressed to a pressure of 2.0 to 2.5 atmospheres and washed in water towers in two stages. Most of the CO_2 is dissolved in the water in the towers, leaving a product containing about 72 percent methane and 16 percent carbon dioxide.

The feasibility of producing methane from Lake Kivu has been amply demonstrated by the pilot plant. However, since the capacity of this plant is very small, there is hardly any measurable effect on the stratification of the lake waters even though the degassed water was returned to the lake at the surface.

4.2 Intermediate Phase

Before full-scale production is started on Lake Kivu, it is most important to observe, under dynamic conditions, the various operating characteristics of the lake with significant volumes of gas being removed and large quantities of water being recycled.

As an intermediate step before full-scale gas production, it is recommended that a plant with an output of about 20 times the capacity of the existing pilot plant be installed (3.0 million cubic feet per day or 30 million normal cubic meters per year). Observations under dynamic conditions would then be possible, using the BGR submarine probe and other pertinent equipment. This will also serve as a demonstration project to gather operating data, determine quantity of gas reserves, and to observe the various effects on lake stratification and the lake environment in general.

4.2.1 Recommended Environmental Study Design

It is essential that the Phase II intermediate-scale production study designed to assess the feasibility of large-scale gas removal from Lake Kivu, include a number of separate investigations directed toward answering questions vital to the long-term use of the gas resources in the lake. A thorough study program will add to the data previously collected, build upon it and provide the needed information to develop sound conclusions regarding feasibility of full-scale gas production. Numerous technical and engineering questions will be addressed during the construction and operation of the plant. In addition, a number of questions related to the environmental aspects of the project must be assessed, including:

- Methane regeneration rate
- Internal lake circulation characteristics
- Density layer stability
- The effect of degasified water return on layer stability
- Biological effects
  - effects of reduced pressure on methane-producing bacteria
  - quantitative assessment of bacteria affected and their regeneration rate
  - biological consequences of degasified water return at various depths

In order to properly assess the long-term environmental consequences of methane removal, these and related questions must be adequately addressed.

4.2.1.1 Methane Regeneration Rate

The source of methane and the regeneration rate have been studied but have not been fully assessed at the present time. Studies have been performed, and estimates of regeneration rate have been made by WHOI and BGR (see Gas Origin in Section 3). These and other studies are of considerable value; however, investigations must continue if a definitive regeneration rate is to be determined.

Sound evidence demonstrates that the origin of the gas is biological rather than geophysical. The mechanism of methane generation by bacteria is fairly well understood (see Section 3.2.4.1 for a discussion on this mechanism). The carbon utilized for the assimilation of methane is either organic carbon derived from decaying plants and animals or inorganic carbon derived from the abundant CO_2 contained in the lake, or possibly both. Most probably the carbon is both organic and inorganic; however, studies need to be undertaken to ascertain conclusively the sources of carbon. *In situ* investigations using a labeled carbon, as well as laboratory investigations using only organic and only inorganic carbon under duplicate laboratory conditions, could possibly determine carbon source.

It is also important to know the rate of production of methane at various depths and areas in the lake. Primary methane production may be occurring in a single stratified layer and diffusing into other layers, in the entire lower water column equally, or in the benthic substrate (lake bottom) and boundary layer between it and the water column above (See Figure 3-4 in Section 3). Studies should be designed to assess this problem, for it may influence the decision as to where in the lake the water should be withdrawn and/or replaced.

4.2.1.2 Internal Lake Circulation Characteristics

Most large lakes have characteristic horizontal circulation patterns peculiar unto themselves and dependent on prevailing winds, topography, location and characteristics of influent and effluent waters. The rate and direction of horizontal circulation at various depths in the lake have been studied by BGR. These studies have shown that there are a characteristic direction and speed of flow at various depths. This information, coupled with more detailed circulation studies of the layers from which water could be withdrawn and returned, would aid in determining the most satisfactory location for water removal and replacement. With detailed information, the intake and outfall pipes/nozzles could be designed to enhance natural flows, to take advantage of the movement of water/gas into and away from the intake/outfall areas.

Knowledge of the horizontal flow characteristics of various layers in the lake would allow modeling of intake and outfall designs and locations and development of a number of alternatives that could be used during the intermediate-phase production. Use of various withdrawal/return scenarios would provide the necessary information for ascertaining the best possible choice for full-scale gas production.

Horizontal flow determinations could be accomplished easily with tracer studies, utilizing dyes or radioactive carbon tagging or other methods. These studies should then be continued during the intermediate-phase operation to ascertain if the water withdrawal and return are affecting the normal circulation pattern. This information would be important in the maintenance of layer integrity and resource renewal.

4.2.1.3 Density Layer Stability

Lake Kivu possesses a number of highly stratified water layers (Figure 3-2, Section 3). This stratification is due to a combination of temperature and salinity factors, with salinity being the major contributor. Lake stratification mechanics and layer stability in Lake Kivu are important because this stratification is responsible for the lake's ability to store its reservoir of compressed gas. The mechanics of this stratification and the stability of the various laye within the lake should be modeled in great detail. Wate withdrawal and discharge at different depths have been modeled by BGR. This model brings into account the quantity of water removed from a specific layer (for gas removal), as well as the quantity of the water returned to a specific layer. With increased modeling efforts, better insight into the net effect of withdrawal from one layer and return to another can be gained.

The potential for lake overturn is a question continually asked relative to Lake Kivu, and with good reason. Lake Kivu has maintained its stability for a long time, and no complete overturn has ever been recorded. It is felt that this stability will remain indefinitely; however, additional stratification stability modeling efforts and quantification of layer integrity would provide a great deal of insight into layer stability and the real potential for partial or complete overturn of Lake Kivu.

4.2.1.4 Environmental Effects

The physical effects of water withdrawal and return must be assessed to protect the integrity of the strata within the lake, and the biological effects must be assessed to assure that there will be no significantly negative impacts on resident populations of aquatic organisms. Plankton (phyto-plankton and zooplankton), bacteria and fish represent important populations in the lake that could be affected by water removal and return. The potential impacts on these populations must be assessed.

4.2.1.4.1 Bacteria

Bacterial flora in the lake are the most probable producers of the methane reserves. The two major types of bacteria directly or indirectly responsible for the gas production are the methane-producing bacteria and the decomposers, respectively. The methane-producing bacteria utilize carbon dioxide and hydrogen in the lake to produce the methane. The source of the carbon dioxide used by the bacteria is not completely understood. The source in the lake is primarily from volcanic emanations, with a secondary source derived from the decomposition of organic matter by decomposers. Evidence indicates that the abiogenetic CO_2 (inorganic) represents a large part of the carbon used by the bacteria for methane production. Certainly the organic CO_2 is also utilized.

Great quantities of water will be withdrawn from the deep layers of the lake and brought to the surface. With this water will be bacterial flora, including the methane-producing species. The effect of pressure reduction and physical handling of the bacteria should be assessed. An important part of the study would be to quantify numbers destroyed and rate of replacement in order to assess the net impact of withdrawal on total population production levels.

Withdrawal of water from one layer (depth) and replacement at another raises a number of questions which must be addressed regarding the bacterial populations. If the species/subspecies population complex varies significantly at different depths, the removal at one depth and replacement at another could potentially upset the species composition. Although it is expected that the species composition is relatively uniform within various density layers, this fact should be assessed.

4.2.1.4.2 Fish

The magnitude of the fishery on Lake Kivu apparently has not been adequately assessed, nor has its potential. WHOI reported that 20 species of fish are known to exist in the lake, while Withington reports that only 11 species are present. Certainly the number of species found in Lake Kivu will not be as high as could be expected under a more normal, less saline condition. The populations of important commercial and sport fish in Lake Kivu should be assessed. Life history data of these species should be considered when deciding on water return location if discharge in the surface layer is a possibility.

4.2.1.5 Degasified Water Return

A crucial question that must be answered concerns the return water location. Every effort must be made to protect the integrity of the layers in the lake. Merely withdrawing water from one layer and discharging it at the surface with no idea of the net effect of the operation would be completely unacceptable, as would a decision to return it to a given depth without a supporting rationale. Additional modeling efforts recommended in Section 4.2.1.3 would be very important in determining the location of water withdrawal and return. Detailed dynamic computer modeling analysis would allow waters of a theoretical or actual salinity and temperature to be discharged at different depths and the results calculated to compare and update the static modeling performed by BGR. Only in such a manner can a sound decision be made relative to return water discharge and its effect on the lake stability, as well as the net effect on the gas reserves. A maximum effort must be expended toward understanding the salinity/temperature stratification stability and the effect of return water.

As discussed above, numerous physical and biological factors must figure in any equation which is used to determine the most appropriate location for degasified water return. The intermediate-scale production proposal will provide an opportunity to answer important questions and address major concerns associated with degasified water return, including the following:

- What effect will withdrawing water at one level and replacing it at another have on the integrity of the layers involved?

- Should water be returned to the level from which it is withdrawn?

- What are the magnitude and direction of flow within each stratified layer, and can these internal flow dynamics allow water to be returned to the same depth from which it is withdrawn without significant gas dilution problems?

- What temperature changes will be brought about by transportation of water from deep in the lake to the surface, and will this change create stability problems when the water is returned?

- If water density is significantly altered by gas removal, temperature change or dilution, can the water be safely returned to a specific density layer without upsetting layer stability?

- Can the density of the degasified water be maintained artificially to retain stratification stability when returned?

- If degasified water is returned at the surface, what will be the magnitude and character of the outfall plume?

- Will this higher salinity water upset the natural stratification in the surface layer, and could it possibly result in a partial overturn or disrupt the natural stability?

- What impacts will the high salinity plume have on the aquatic flora and fauna?

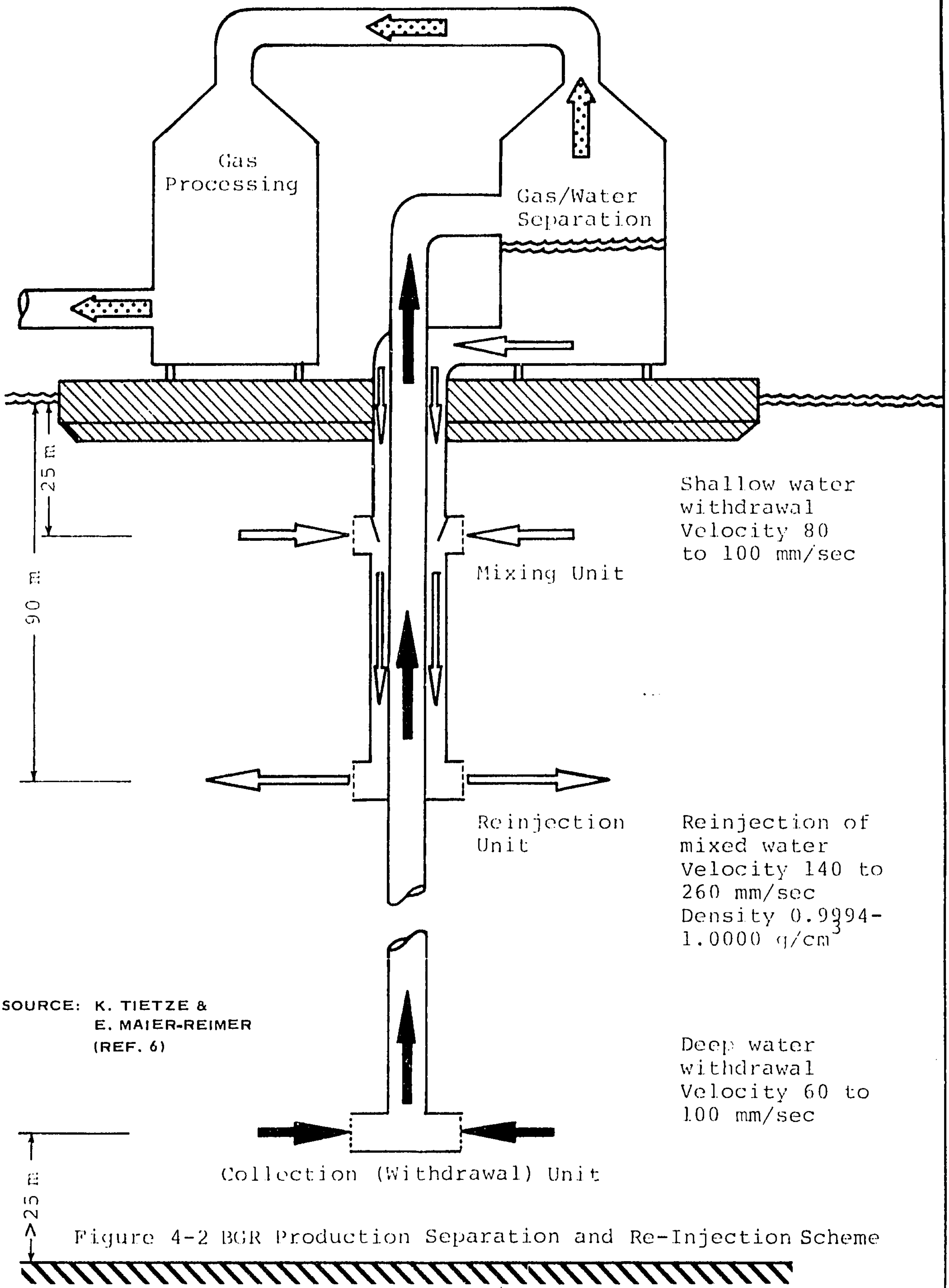
- What effects will the high salinity plume have on the naturally increasing salinity of the surface layer? Will surface discharge significantly increase lake aging?

Intermediate-scale production would provide the data needed to assess these and other important questions concerning removal of methane from the lake and associated water circulation.

4.2.2 Intermediate Phase Plant Design Options

The UCB gas lift production process is envisioned for all intermediate phase plant options. Gas/water lift would possibly require four 30-inch diameter pipelines (750 millimeters) and two gas-water separators. The major difference between the intermediate-phase plant and the existing pilot plant would be that, in the intermediate phase plant, the degassed water would be returned in horizontal pipelines, after being mixed with some surface water, to a layer of equivalent salinity, to retain the integrity of the water strata as recommended by BGR (Figure 4-2). Processing of the gas will vary with the purity requirements of the final plant product, whether it is to be pipeline gas or methanol. It is recommended that the intermediate-scale plant be operated for at least three years before a full-scale operation is designed.

The reconnaissance investigation to Rwanda revealed that transmitting methane gas by pipeline at relatively low flow



SOURCE: K. TIETZE & E. MAIER-REIMER (REF. 6)

Figure 4-2 BGR Production Separation and Re-Injection Scheme rates would be uneconomic. The hilly and mountainous terrain in Rwanda further makes a methane gas pipeline of any major length too expensive to construct and operate. Short pipelines, however, could be used to transport methane gas to industry located near Lake Kivu and near a gas production operation.

As is pointed out in the Gas Utilization Economics Section of this report (Section 5) which follows, methanol is the most versatile and clean-burning of all the fuels that could be derived from the Lake Kivu methane. Methanol can be used as a blend for imported gasoline and a substitute for imported fuel oil and kerosene. Further, methanol could be used for domestic lighting and cooking, thereby reducing the need for burning diminishing wood supplies. It is also easily distributed by using existing trucking companies in Rwanda and shipping companies that operate on Lake Kivu.

Three possible intermediate-phase methanol plants were examined. Schematic drawings of these three plants are shown as Figures 4-3, 4-4 and 4-5 described as Cases "A", "B" and "C".

4.2.2.1 <u>Case "A" Plant</u>

The Case "A" Plant shown in Figure 4-3 would produce 60 metric tons of methanol per day. A total of 13 million cubic feet per day of dissolved gases would be removed from the lake to produce 1.9 million cubic feet per day of methane to feed the methanol production process. Since the low pressure UCB water tower wash process to remove CO_2 would not provide methane gas of sufficient purity, a Benfield hot potassium carbonate process would be used to remove CO_2 from

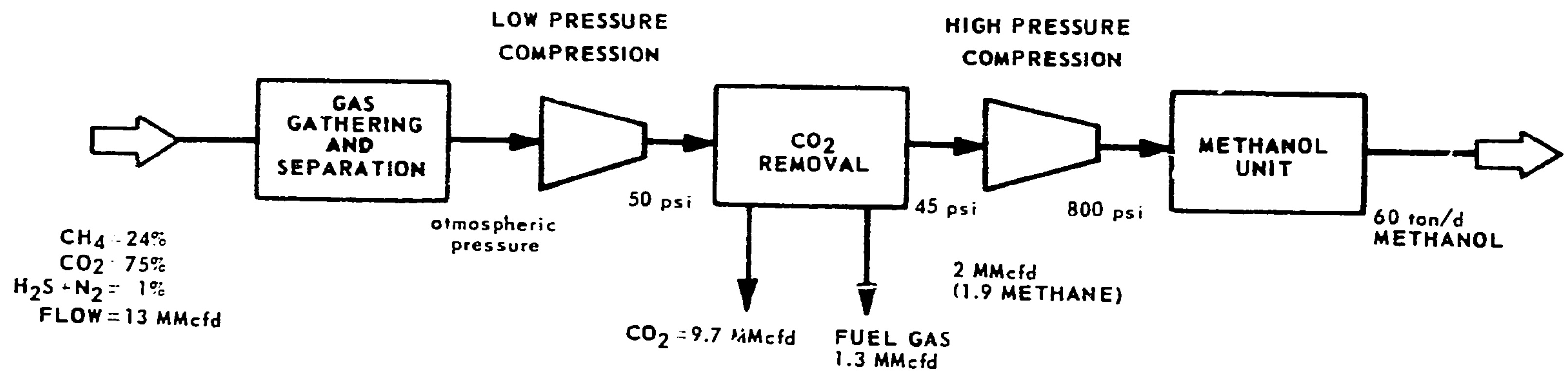


Figure 4-3 Case "A" Plant

the methane gas. The hot potassium carbonate process would use as fuel part of the methane produced and provide 95 percent pure methane to a methanol production unit utilizing the process of Imperial Chemical Industries, Ltd. of Great Britain (ICI).

The estimated installed cost of the Case "A" Plant would be \$22.35 million, which includes gas gathering, gas separation, CO_2 removal and methanol production. A detailed breakdown of the estimated cost of Case "A" Plant follows.

ESTIMATED COST DETAIL
CASE "A" PLANT

Gas Gathering and Separation	\$6,000,000
Low Pressure Compression	460,000
CO_2 Removal	1,940,000
High Pressure Compression	200,000
Methanol Production Unit	4,750,000
Support Equipment	1,000,000
Freight and Installation	5,000,000
Engineering	3,000,000
TOTAL	\$22,350,000

Assuming a 20-year amortization at 10 percent interest, the estimated annual operating cost of the Case "A" Plant would be \$3,960,000. The detail of the estimated annual operating cost of the Case "A" Plant is shown below.

ESTIMATED ANNUAL OPERATING COST
CASE "A" PLANT

Capital (20 years @ 10% interest)	\$2,625,000
Maintenance	250,000
Operating Labor	350,000
Chemicals and Other Materials	130,000
Electric Power	370,000
Insurance	235,000
TOTAL	\$3,960,000

If the Case "A" Plant operates 340 days per year with production of 60 metric tons per day, it will produce 20,400 metric tons of methanol per year. Therefore, 20,400 metric tons of methanol would be produced per year at a cost of $3,960,000 or $194 per metric ton.

4.2.2.2 Case "B" Plant

The Case "B" Plant shown in Figure 4-4 which is 25 percent larger than the Case "A" Plant, would produce 75 metric tons of methanol per day. A total of 16.67 million cubic feet per day of dissolved gases would be removed from the lake to produce 2.38 million cubic feet per day of methane to feed the methanol production process. A Benfield hot potassium carbonate process would be used to remove CO_2 from the methane gas as in Case "A". Ninty-five percent pure methane would then be provided to an ICI methanol unit to produce 75 metric tons per day of methanol.

The estimated installed cost of the Case "B" Plant would be $24.537 million, which includes gas gathering, gas separation, CO_2 removal and methanol production. A detail estimate of the installed cost of the Case "B" Plant is shown below.

ESTIMATED COST DETAIL
CASE "B" PLANT

Gas Gathering and Separation		$ 6,858,000
Low Pressure Compression		575,000
CO_2 Removal		2,425,000
High Pressure Compression		250,000
Methanol Production Unit		5,429,000
Support Equipment		1,000,000
Freight and Installation		5,000,000
Engineering		3,000,000
	TOTAL	$24,537,000

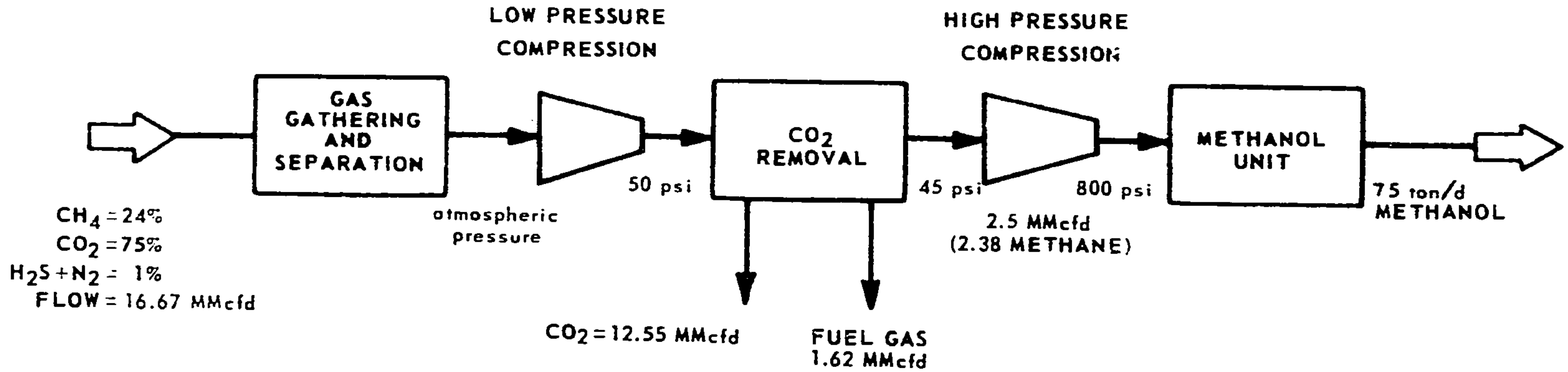


Figure 4-4 Case "B" Plant

Assuming a 20-year amortization at 10 percent interest, the estimated annual operating cost of the Case "B" Plant would be $4,505,000. The detail of the estimated annual cost of the Case "B" Plant is shown below.

ESTIMATED ANNUAL OPERATING COST
CASE "B" PLANT

Capital (20 years @ 10% Interest)	$2,882,000
Maintenance	300,000
Operating Labor	450,000
Chemicals and Other Materials	160,000
Electric Power	463,000
Insurance	250,000
TOTAL	$4,505,000

If the Case "B" Plant were to operate 340 days per year with production of 75 metric tons per day, it would produce 25,500 metric tons of methanol per year. Therefore, 25,500 metric tons of methanol would be produced per year at a cost of $4,505,000 or $177 per metric ton.

4.2.2.3 Case "C" Plant

The Case "C" Plant shown in Figure 4-5, would produce 95 metric tons of methanol per day. A total of 13.3 million cubic feet per day of dissolved gases would be removed from the lake to produce 3.0 million cubic feet per day of methane to feed the methanol production process. The CO_2 would be removed in the Case "C" Plant by using the Union Chimique Belge high pressure water wash process. The process will provide 92 percent pure methane to the ICI methanol production unit and eliminate the need for fuel gas consumed in CO_2 removal. The electric consumption for pumping water is 1.04 kilowatt hours per normal cubic meter of methane gas produced. Therefore, 3448 kilowatt hours of electricity

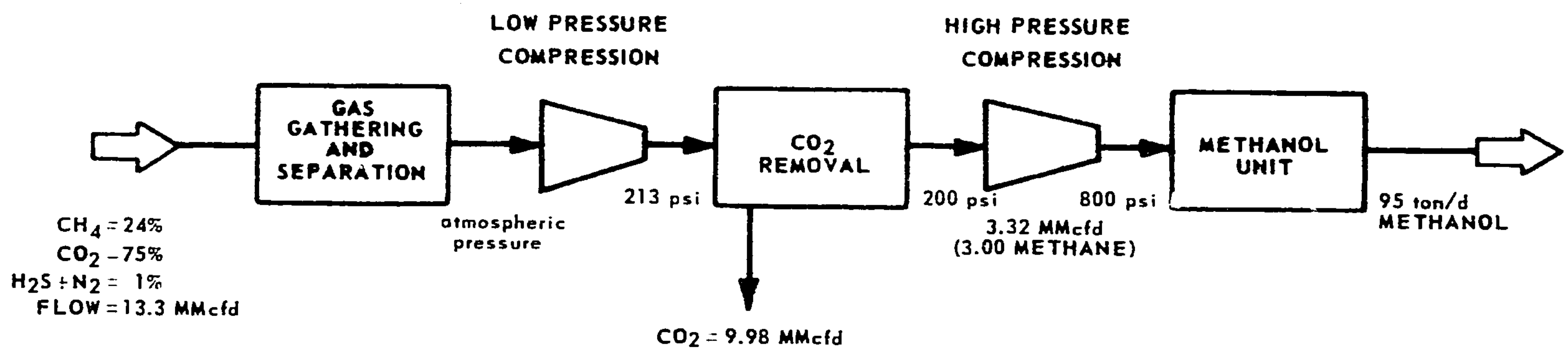


Figure 4-5 Case "C" Plant

would be required for pumping water; and 2,064 kilowatt hours would be needed for compressing gas.

The estimated installed cost of the Case "C" Plant would be $24.001 million, which includes gas gathering, gas separation, CO_2 removal and methanol production. This estimate is shown in detail below.

ESTIMATED COST DETAIL
CASE "C" PLANT

Gas Gathering and Separation		$ 6,000,000
Low Pressure Compression		800,000
CO_2 Removal		1,745,000
High Pressure Compression		200,000
Methanol Production Unit		6,256,000
Support Equipment		1,000,000
Freight and Installation		5,000,000
Engineering		3,000,000
	TOTAL	$24,001,000

Assuming a 20-year amortization at 10 percent interest, the estimated annual operating cost of the Case "C" Plant would be $4,730,000.

An electric cost of 2¢ per kilowatt hour was used in this estimate as well as the Case "A" and "B" estimates, as abundant hydroelectric power should be available in the near future in Rwanda. If hydroelectric power is not available, all pumps and compressors can be designed to use methane gas from Lake Kivu and operated at a cost that would be a very close equivalent to 2¢ per kilowatt hour electricity.

ESTIMATED ANNUAL OPERATING COST
CASE "C" PLANT

Capital (20 years @ 10% Interest)	$2,819,000
Maintenance	350,000
Operating Labor	450,000
Electric Power	906,000
Insurance	205,000
TOTAL	$4,730,000

If the Case "C" Plant operates 340 days per year with production of 95 metric tons per day, it would produce 32,300 metric tons of methanol per year. Therefore, 32.300 metric tons of methanol would be produced per year at a cost of $4,730,000 or $146 per metric ton.

4.2.2.4 Case "A", "B" and "C" Summary

A summary of the examinations of the Case "A", "B" and "C" plants with respective gas output to the methanol unit of 1.90, 2.38 and 3.00 million cubic feet per day (MMcf)/day follows.

ESTIMATED COST SUMMARY
CASE "A", "B" AND "C" PLANTS

	Case "A"	Case "B"	Case "C"
Raw gas throughput, MMcf/day	13.00	16.67	13.30
Methane Output, MMcf/day	1.90	2.38	3.00
Methanol Output, ton/day	60	75	95
Capital Cost, million $	22.350	24.537	24.001
Annual Operating Cost, million $	3.960	4.505	4.730
Assumed cost of electricity, ¢/kwh	2	2	2
Cost of Methanol, dollars per Metric ton	194	176	146

With 2.208 units of methanol to yield the same heating value as one unit of gasoline, 2.196 units of methanol to equal the heating value of one unit of kerosene, and 2.032 units to equal the heating value of one unit of fuel oil, the relative cost of the above fuels is shown below.

PETROLEUM PRODUCT HEATING VALUE COST COMPARISON
CASE "A", "B", AND "C" PLANTS
(Dollars per Metric Ton)

Product	Case "A"	Case "B"	Case "C"
Methanol alone	$194	$177	$146
Methanol as gasoline	429	390	323
Methanol as gasohol	194	177	146
Methanol as kerosene	426	388	322
Methanol for lighting	194	177	146
Methanol as fuel oil	394	359	298

These various product costs as they relate to methanol and the economy of Rwanda depend on how the methanol is used and are discussed in detail in the Gas Utilization Economics section of this report (Section 5).

4.3 Full Scale Production Phase

BGR has formulated the most complete three-dimensional picture of the lake waters available at this time. It has also developed a three-dimensional, numerical computer model to investigate various rates and patterns of water withdrawal and reinjection. In addition, a radial model was developed to study fluid flow in the vicinity of a withdrawal point.

BGR carried out numerous runs with these numerical models and concluded that methane production rates up to 100 million cubic feet per day (one billion normal cubic meters per year) may be possible and might require production and processing from offshore platforms.

BGR states that production at such high rates would be contingent upon very careful controls and a gradual scaling up from an intermediate-scale plant. These controls refer to production from perforated horizontal pipes, and returning the degassed water to the lake under stringent conditions of density, depth and rate of injection. These controls would be used to minimize problems of mixing, layer perturbation and internal wave action. BGR recommends mixing the degassed water with surface water in the ratio 1 to 1.5, and returning the mixture to a depth of 200 to 300 feet (60 to 90 meters), to a layer of equal density.

Development of any project approaching this scale is contingent upon careful monitoring of the lake during the proposed intermediate-phase program. Dynamic measurements will make it possible for the numerical model to be matched and rematched as more performance history is generated. In this way the model will gradually become more and more reliable as a tool for long-term prediction of the behavior of Lake Kivu.

In 1972, Preussag, A.G. (a German Company), studied various methods of land based and offshore production and separation configurations for rates up to seven million cubic feet per day. It considered both automatic gas lift (UCB "autopompage" principle) and submersible pumping. It recommended offshore production methods for uniform reservoir withdrawals; however, treatment and processing would be onshore or offshore. In the latter case, only purified gas would be transported to shore, instead of the whole gas stream.

Preussag compared the hot potassium carbonate solution process for removing CO_2 with the a water wash process. It recommended the latter as being less complex and requiring a lower capital investment. The disadvantages are in handling enormous amounts of wash water and additional loss of methane.

As stated above, numerous methods have been suggested for full-scale production of methane gas from Lake Kivu; however, this magnitude of production can only take place after an intermediate step is taken. Observation of gas production from Lake Kivu needs to be made under dynamic conditions so that data can be obtained concerning gas reserves, lake stratification and the lake environment in general. Therefore, a full-scale production phase should only take place after successful intermediate-phase operations have been demonstrated.

5.0 GAS UTILIZATION AND ECONOMICS

Although the industrialized countries of the world face serious problems with the world energy crisis, their plight is far less severe than that faced by most developing countries. The 1973 to 1974 oil embargo and fourfold increase in oil prices have already demonstrated the industrialized countries' vulnerability to arbitrary supply and price manipulation. The industrialized nations continue to face supply and price vulnerability, large and increasing balance of payment deficits, and resulting constraints on economic growth.

5.1 World Oil Prices and the Economy of Developing Nations

The dramatic 1973 to 1974 world oil price increases contributed significantly to the worst global recession since the Great Depression in the late 1920's and the early 1930's. The massive oil price increases since 1973 have most adversely affected those developing countries that lack domestic oil supplies. Their expenditures for petroleum rose from about $4 billion in 1973 to $12 billion in 1975. The indirect cost to the economies of the developing countries was even more pronounced. The recession and inflation in the industrialized countries slackened the demand for developing countries' exports, and from 1973 to 1975 the foreign debt of developing countries rose from $67 to $117 billion.

Rising oil prices and uncertain energy supplies experienced during recent months are posing the gravest threat to the world economy since the recession of 1974 to 1975. World demand for petroleum is currently outstripping supply by 1.5 million barrels per day with prices up by more than 35 percent since December, 1978. Political leaders around the world and economists alike fear that shortages could grow and prices might rise to more damaging heights in the immediate future. Oil bills are rising at alarming rates along with balance-of-payments deficits in developing countries that do not produce petroleum. The combined balance-of-payments deficits of these nations will rise to at least $40 billion this year from $31 billion last year, according to the International Monetary Fund.

The developing nations cannot significantly reduce their energy consumption since they are not large energy users. As increasing amounts of foreign exchange are expended for energy imports, other development needs suffer.

The quadrupling of oil prices introduced a significant structural distortion into the international payments mechanism. Debt service amounted to about 15 percent of the world's export receipts in 1976. As a result, many countries are finding it more difficult to obtain additional loans from the commercial monetary markets. The balances held by oil producing countries have been invested mainly in industrialized countries in short-term securities, although a shift to long-term investments is occurring. Most of these funds have been invested in the United States and Europe, with only limited amounts flowing into developing countries. Ironically, it is the developing countries that suffer most from the energy crisis and have the greatest need for a compensating flow of capital.

During the last years of the 20th century, both industrialized and developing countries will have to reduce significantly their reliance on imported petroleum and make greater use of domestic energy sources. For the long term, countries of the world will need to develop their renewable energy resources. If steps are not taken soon to prepare for this transition, the world will face serious economic and political problems.

5.2 Rwandan Economy and its Gross National Product

Rwanda is one of the most densely populated countries in Africa, as well as one of the smallest in land area. Rwanda is landlocked and isolated and has very limited mineral resources.

Rwanda keeps an open commercial policy with all countries, and the relationship it has with neighboring nations is strong. In addition to the official commerce, there is an important parallel market with its immediate neighbors, that of trading or exchanging one product for another--bartering. This trade remains undocumented and unrecorded.

Rwanda's debt to foreign nations increased in 1977 to a total of more than $109 million. Payment of this debt went from half a million dollars in 1976 to $2.4 million in 1977. Foreign aid, private and public, was greater than $87 million in 1977 against $68 million in 1976, or an increase of 27 percent. The bulk of this aid comes from Belgium, followed by the United Nations and its agencies, and then France and West Germany, and the European Development Fund.

The Gross National Product of Rwanda has registered a high rate of growth. It went from $250 million in 1974 to $630 million in 1976, a 152 percent increase in two years. The agricultural sector benefited mainly because of the increased price of coffee and tea on the world market. Income from the mining industry grew as a result of increasing world price for cassiterite and wolfram, ores of tin and tungsten, respectively. The startup of new industries and the expansion of construction led to a five-fold increase in the industrial sector in five years. The economic stability of the country during the last few years has led to the continued development of the industrial and commercial sectors.

Agricultural products contributed 89 percent of the commodity exports by value in 1977. Coffee alone produced 73 percent of all exports and tea, pyrethrum and livestock products accounted for an added 14 percent. Increasing unfavorable conditions of trade have meant that Rwanda's deficit has been widening since 1970 except for the significant change in 1973.

Land devoted to the production of agricultural crops increased significantly from 1976 to 1977; however, the overall productivity decreased. During the last five years, the surface area farmed increased 25 percent; yet the productivity increased only 21 percent, resulting in a net reduced productivity. Reduced yield was noted for bananas, rice and potatoes, while production of corn and legumes increased slightly. The primary reason for the reduced yield is the poor quality of new land placed into production. The country faces a shortage of high quality land to add to crop production, and, therefore, a shortage in foodstuff per capita. This will probably get worse as the population continues to grow. Rwanda is very likely to reach the minimum food requirement set by the Food and Agriculture Organization of the United Nations (FAO) of 2100 kilocalories per day per capita.

The overall economic condition of Rwanda is favorable, and it will continue to enjoy a favorable economy providing a few changes take place. These changes include productivity improvements of the principal crops whose yield per hectare are decreasing, as well as improvement of the nation's fiscal and employment program. Prices are going up while salaries remain constant, which decreases buying power. In 1974, per capita income was about $60.00; in 1975, $115; in 1976, $145; and, in 1977, $157.

5.2.1 Balance of Trade

Imports into Rwanda increased significantly from $58.6 million in 1974 to $114.9 million in 1977. Imports come mainly from Belgium and Japan. The following table shows the balance of trade during the period from 1970 to 1977. As can be seen in Table 5-1, the country continues to remain in a deficit position. The deterioration in the balance of trade in 1974 to 1975 is not as grave as it appears because a portion of the imports was in the form of gifts from other countries and does not represent a debt. The significant improvement between 1975 and 1976 was due to the dramatic rise in the export price of coffee and tea. The table does not take into account the unrecorded merchandise traded with neighboring countries, which may represent a significant amount.

Table 5-1
BALANCE OF TRADE, 1970 to 1977
MILLIONS OF DOLLARS

	1970	1971	1972	1973
Export	26.963	24.274	19.514	30.290
Import	31.628	35.925	34.595	30.642
Balance	-4.665	-11.651	-15.081	-.352

	1974	1975	1976	1977
Export	37.598	42.591	81.903	94.916
Import	58.634	96.989	104.422	114.999
Balance	-21.036	-54.398	-22.519	-20.083

Despite an adverse balance of trade, Rwanda has been able to increase its foreign exchange reserves since 1972 by capital inflows in the form of external assistance from other countries or multilateral agencies.

Rwanda has no direct access to the sea and depends on the seaports of neighboring countries and routes through Tanzania, Uganda and Kenya for its foreign trade. Dar-es-Salaam, the port of Tanzania, is approximately 1100 miles (1770 kilometers) from Rwanda. It is linked to Rwanda by two overland routes: one through Rusumo which connects at Mwanza with the railroad to Dar-es-Salaam; and another, a 180-mile (290 kilometers) trip by road to Lake Tanganyika and 130 miles (209 kilometers) by barge to the Kigoma-Tobora-Dar-es-Salaam railroad, then 800 miles (1287 kilometers) by rail to Rwanda. Mombasa, the port of Kenya, is approximately 1100 miles (1770 kilometers) from Rwanda, 350 miles (563 kilometers) by road and 750 miles (1207 kilometers) by rail.

5.2.2 Methane Exploitation

One of the bright spots in the future of Rwanda is the large methane reserve in Lake Kivu. Exploitation of these reserves can reduce payments that must be paid for imported petroleum and provide energy to produce export products. The methane from Lake Kivu can be used directly as methane gas or further processed into methanol. Methanol is perhaps the most versatile and clean-burning of all the fuels that could be derived from the Lake Kivu methane. Commonly known as wood-alcohol or methyl-alcohol, methanol has superior combustion and emission characteristics. During boiler and gas-turbine burn tests, sulfur dioxide levels remain undetectable, concentrations of nitrogen oxides are lower than those recorded when natural gas is fired, and emissions are essentially invisible.

The concept of using methanol as a fuel received much attention in the late-1960's and early-1970's when industrialized nations sought economical methods for transporting large quantities of natural gas from wells in remote areas to factories. Many engineers thought methanol was safer, cheaper, and easier to ship than liquefied natual gas. In addition, end users had the option of utilizing it as a liquid or regasifying the methanol. The oil embargo and the general unstable nature of the world energy market in the mid-1970's, however, scuttled some key projects overseas, and the methanol concept received much less attention.

But the dramatic increase in fuel prices caused by the oil embargo helped to stimulate interest in processes for converting coal, tar sands, oil shale, and biomass to methanol. These processes, previously regarded as uneconomic, suddenly became attractive. Today commercial viability of methanol production is close to being assured, in part because of various environmental regulations that would restrict pollutant emissions from stationary combustion sources to very low levels.

5.2.3 Petroleum Imports - Present and Future

At the present time, Rwanda is completely dependent on foreign sources for its petroleum products, for the country does not have natural reserves and must, therefore, import 100 percent of the nation's needs. This complete reliance on foreign oil, coupled with the fact that all land routes for petroleum imports must pass through neighboring countries, places Rwanda's petroleum costs in constant flux and petroleum availability in constant question.

Table 5-2 shows the level of petroleum product imports from the period of 1974 through 1977. In looking at the total petroleum imports, it can be seen that between 1974 and 1977 the quantity increased by 57.4 percent (22,910 to 36,159 metric tons) while the cost for the petroleum escalated by 151.9 percent ($4,420,652 to $11,136,956). Between 1974 and 1977 the amount of kerosene imported decreased by 28.2 percent; yet the money spent on kerosene increased by 13.4 percent. Between 1974 and 1977 fuel oil imports increased by over 248 percent while at the same time the costs for that product increased by over 454 percent.

Table 5-2
IMPORTATIONS OF PETROLEUM PRODUCTS FROM 1974 THROUGH 1977

	1974		1975		1976		1977		
	Metric Tons	Dollars	Metric Tons	Dollars	Metric Tons	Dollars	Metric Tons	Dollars	% Increase 1974 - 1977
Kerosene	4,889	951,087	5,725	1,295,652	4,118	1,059,782	3,512	1,078,260	-28.2% wt.
(increase)			17.1%	36.2%	-28.7%	-18.2%	-14.7%	1.7%	13.4% $
Diesel	8,158	1,422,826	10,541	2,131,521	14,638	3,844,565	12,004	3,294,565	47.1% wt.
(increase)			29.2%	49.8%	38.9%	80.4%	-18.0%	-14.3%	131.6% $
Fuel Oil	705	95,652	401	95,652	1,294	236,956	2,456	530,434	248.4% wt.
(increase)			-43.0%	0%	222.7%	147.7%	89.8%	123.9%	454.5% $
Gasoline	9,158	1,951,086	12,406	2,964,130	15,097	4,733,695	18,087	6,233,695	97.5% wt.
(increase)			35.5%	51.9%	21.7%	59.7%	19.8%	31.7%	219.5% $
TOTAL	22,910	4,420,652	29,073	6,486,956	35,147	9,875,000	36,059	11,136,956	57.4% wt.
			26.9%	46.7%	20.89%	52.2%	2.6%	12.8%	151.9% $

Figures 5-1 and 5-2 show actual petroleum imports for Rwanda from 1974 to 1977 and predicted imports for Rwanda from 1977 to 1985. The actual import escalation data points were those recorded by the National Bank of Rwanda. The predicted estimates were based on a logarithmic fit of the curve demonstrated by the recorded historical data and, also, as an assumed percentage increase. It is felt that the cost estimates for import escalation are conservative. The estimated growth of Rwanda's petroleum needs, however, is more difficult to predict due in part to the small size of the nation and the many unidentified limiting factors that pertain to domestic, commercial and industrial expansion. Funds spent on petroleum imports increased 46.7 percent between 1974 and 1975, 52.2 percent between 1975 and 1976 and 12.8 percent between 1976 and 1977, while at the same time the trend in demand was declining as is demonstrated in Table 5-2. However, using an estimated 10 percent annual increase in consumption, based on the 1974 to 1977 figures, should be conservative. Figures 5-1 and 5-2 predict that by 1985 Rwanda will be importing about 77,000 metric tons of petroleum annually at an average cost of approximately $660 per ton (assuming historic/predicted trend is realized). In 1977 it imported 36,059 metric tons at an average cost of about $309 per ton. Based on the historical trend, it is predicted that, in 1985, the price of gasoline to Rwanda will be $738 per metric ton, kerosene would be $657 per metric ton, fuel oil $462 per metric ton and diesel fuel $586 per metric ton.

Actual petroleum products volume and cost data to Rwanda were available only through 1977; and, as aforementioned, the values from 1977 through 1985 were predicted (Figures 5-1 and 5-2). However, actual refinery figures are

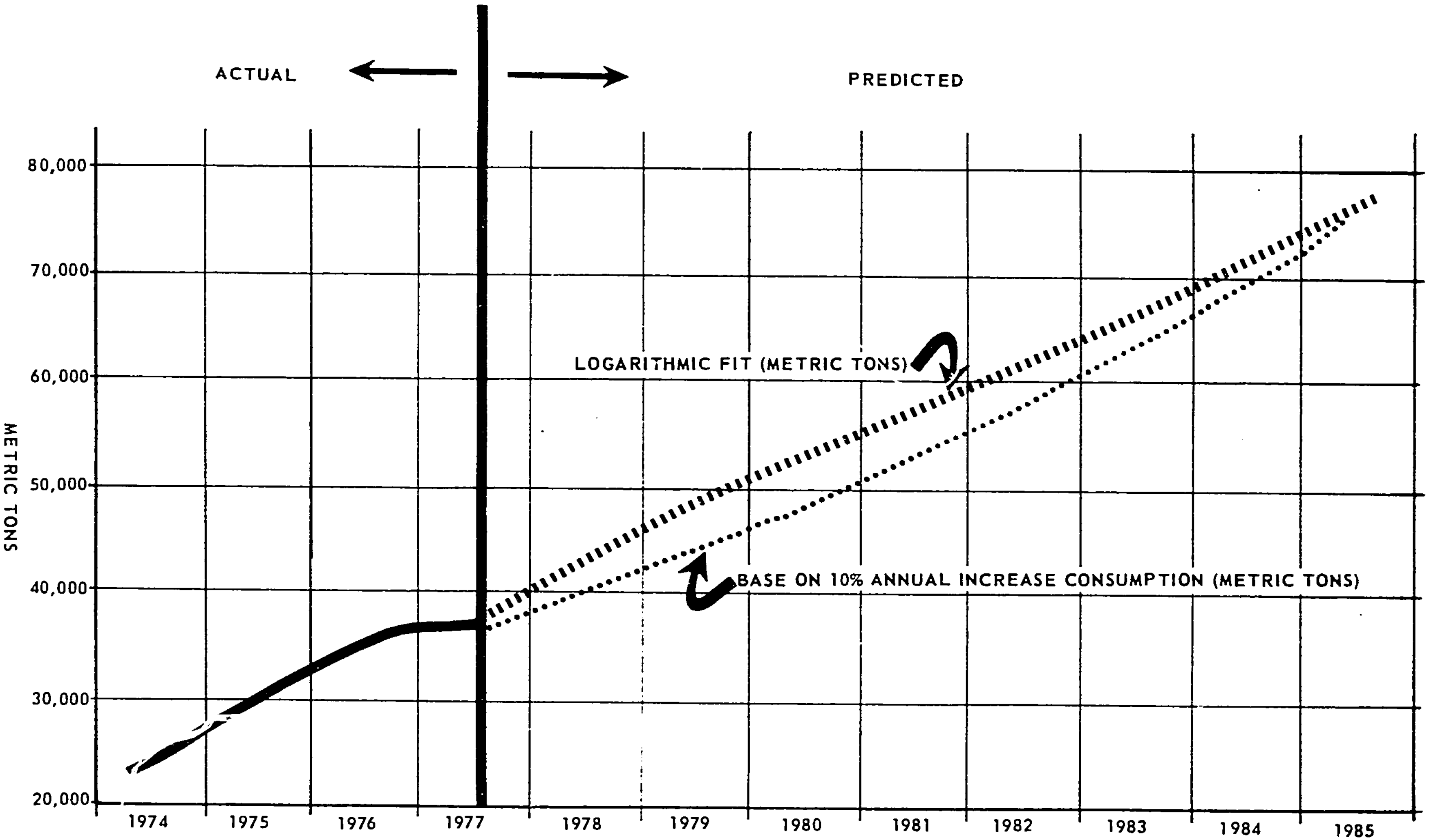


Figure 5-1 Actual and Predicted Petroleum Imports 1974 through 1985

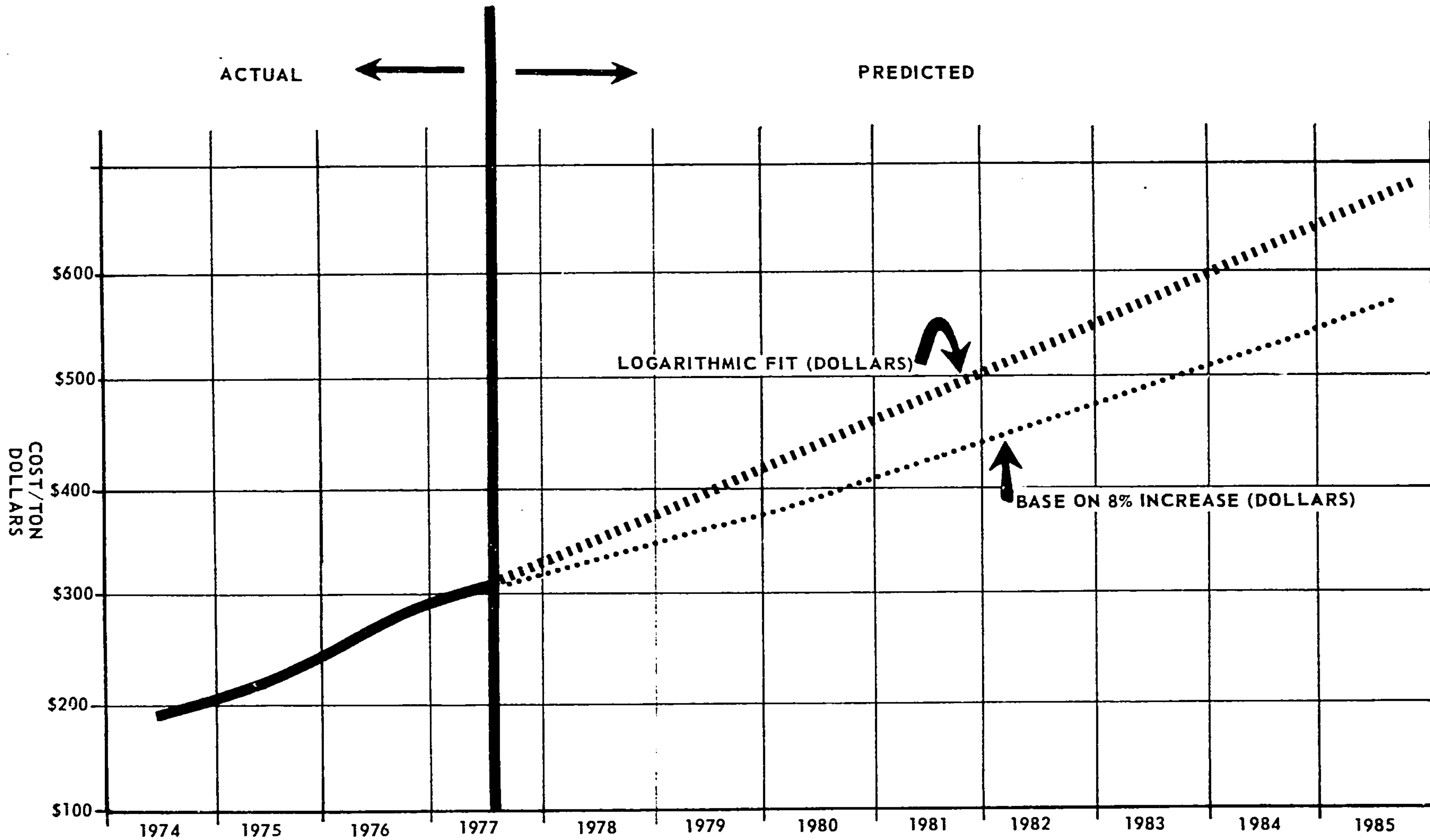


Figure 5-2 Actual and Predicted Petroleum Imports 1974 through 1985

available through June, 1979 (Table 5-3). If one compares these data with estimates predicted for Rwanda, it can be seen that the cost percentage increase predicted by logarithmic curve fitting agrees well with actual increases at the Shell refinery in Iran. Product cost from the Shell refinery from December, 1977, through June, 1979, escalated an average of 37 percent while, for the same period of time, the increase predicted for Rwanda was 37 percent. This cost increase is FOB refinery and does not take into account delivery cost to Rwanda or the recent sharp increase in OPEC oil prices to become effective July 1, 1979 of 20 to 30 percent.

Table 5-3. REFINERY PRODUCT CARGO PRICES F.O.B. SHELL REFINERY - IRAN.

Date	Product	90 Oct. Gasoline	Kerosene	Diesel	No. 5
1977	Dec.	42.0	41.5	37.5	11.45
1978	Jan.	42.0	43.0	38.5	11.55
	Feb.	42.0	43.0	38.5	11.55
	Mar.	42.0	43.0	38.5	11.55
	Apr.	42.0	43.0	38.5	11.15
	May	42.0	43.0	38.5	11.15
	June	42.0	43.0	38.5	11.15
	July	42.0	43.0	39.5	10.95
	Aug.	42.0	43.0	39.5	10.95
	Sept.	42.0	43.0	39.5	10.95
	Oct.	42.0	43.0	39.5	10.75
	Nov.	42.0	43.0	39.5	10.75
	Dec.	42.0	43.5	40.5	10.50
1979	Jan.	45.5	47.0	43.0	11.00
	Feb.	48.7	49.5	45.5	11.20
	Mar.	48.7	49.5	45.5	12.00
	Apr.	54.7	53.5	49.5	13.60
	May	59.5	55.5	50.5	14.75
	June	59.5	55.5	50.5	15.95
Net Increase Dec. 1977 to Jan. 1979		41.7%	33.7%	34.7%	39.3%

5.3 Methane Exploitation and Its Effect on Rwanda's National Economy

Based on the predicted estimates, Rwanda will be spending about $51 million on petroleum imports by 1985--capital that will be leaving the country. An intermediate-scale methanol plant could produce up to 95 metric tons per day of methanol, thereby significantly reducing Rwanda's petroleum imports. Depending on the use of the methanol (heating, cooking, lighting, transportation, etc.), the savings in the balance of payment would approach $17 million per year. An additional important factor is that, following 1985, the cost of imported petroleum products will certainly continue to rise at an alarming rate while the increased cost of methane development can be kept to a minimum. This fact makes the intermediate and full-scale methane development operations extremely economical while at the same time reducing Rwanda's dependence on foreign petroleum and reducing its foreign currency burden.

In looking at the total petroleum distillate imports into Rwanda between 1974 and 1977, approximately 15 percent was kerosene, 37 percent diesel, 4 percent fuel oil and 44 percent gasoline. It is estimated that, in 1985, Rwanda will import nearly 34,000 tons of gasoline, 12,000 tons of kerosene, 3,000 tons of fuel oil and 28,000 tons of diesel. Using the 1985 projections, methanol could be used to replace approximately 7,000 tons of gasoline imports, 12,000 tons of kerosene, and 3,000 tons of fuel oil (Table 5-4). As is demonstrated in Table 5-4, Rwanda would experience an annual capital savings of approximately $15 million due to intermediate-phase methanol development. Assuming a 95 metric ton per day methanol production plant, approximately

10,300 metric tons per year of methanol (or equivalent amount of methane gas) would be available for other domestic, commercial or industrial uses. If a 2 to 1 methanol-to-petroleum product substitution ratio is assumed (heating value comparison), the 10,300 tons of methanol would replace another 5150 metric tons of petroleum imports. At an assumed replacement cost of $462 per metric ton (fuel oil cost) this would represent an additional capital savings of $2,379,300, for a total savings of more than $17 million per year. If the capital and operating costs of the methanol plant are deducted, a saving of $12 million per year would be realized on a direct cash basis alone.

Table 5-4. PETROLEUM PRODUCT IMPORT REDUCTIONS AND CAPITAL SAVINGS AS A RESULT OF INTERMEDIATE-PHASE METHANOL DEVELOPMENT.

	Predicted 1985 Import (Metric Tons)	Estimated Replacement (Metric Tons)	Predicted 1985 Product Cost (Dollars per Metric Ton)	Capital Savings From Methanol Dev. (Dollars)
Gasoline	34,000	7,000	738	5,166,000
Kerosene	12,000	12,000	657	7,884,000
Fuel Oil	3,000	3,000	462	1,848,000
Diesel	28,000		586	----
Total	77,000	22,000	---	14,898,000

If one compares methanol with other petroleum products on a Btu basis, it appears that more than twice as much methanol would have to be used to replace petroleum distillates, for methanol is rated at approximately 8,500 Btu's per pound while petroleum distillates are in the range of 17,300 to

18,800 Btu's per pound. Although there are about 120 percent more Btu's per quantity of gasoline than of methanol, there is little or no difference in the performance between gasohol (15 to 20 percent blend) and gasoline. It would take approximately 1.03 gallons of gasohol to take a vehicle as far as 1.0 gallon of gasoline, and the figure may be less than 1.03 depending on the vehicle. If one factors some of the beneficial aspects of the gasohol, (cleaner burning, reduced emissions, less carbon buildup, longer engine life, etc.) the difference could be considered a one-for-one substitution. Likewise, if one uses methanol lighting (mantle or pressurized type), there would probably be little or no net reduction in lighting units for methanol and kerosene.

The world use of methanol could even be greater in the future with the interest and work currently being demonstrated. Research is underway to use methanol as a primary fuel. A car can also run on pure methanol, but the carburetor must be modified (re-jetted). Advantages of methanol over gasoline are higher octane rating, higher fuel efficiency and lower carbon monoxide emissions. Instead of directly injecting methanol into an engine of a vehicle or that of a prime mover, the methanol first could pass through a catalytic converter similar to those used on today's auto exhaust systems. The converter would change the methanol into hydrogen, one of the most powerful fuels known today, which then would be fed into the engine. Not only could this process boost the power output of the methanol, it would also eliminate the storage and safety problems associated with hydrogen or other gases.

With locally developed energy available to Rwanda, industry can be expanded. Table 5-5 shows various possible future uses of energy produced from Lake Kivu, and Figure 5-3 depicts the geographic location of potential users. The sources for this information were the United Nations, European Development Fund, and the Rwanda government.

Long-term uses of energy might include: cassiterite refining, nickel refining, metal and salt extraction from lake waters, iron foundary uses, tungsten enrichment, and fertilizer manufacture.

After a review of various studies of Lake Kivu and a review of the needs of Rwanda, it appears that the time has come for a total development effort to utilize the energy resources of Lake Kivu. All professionals contacted by Williams Brothers Engineering Company in the United States, Europe, and Africa, agreed that further development efforts were needed to demonstrate the methane reserves of the lake and to develop optimum production technology.

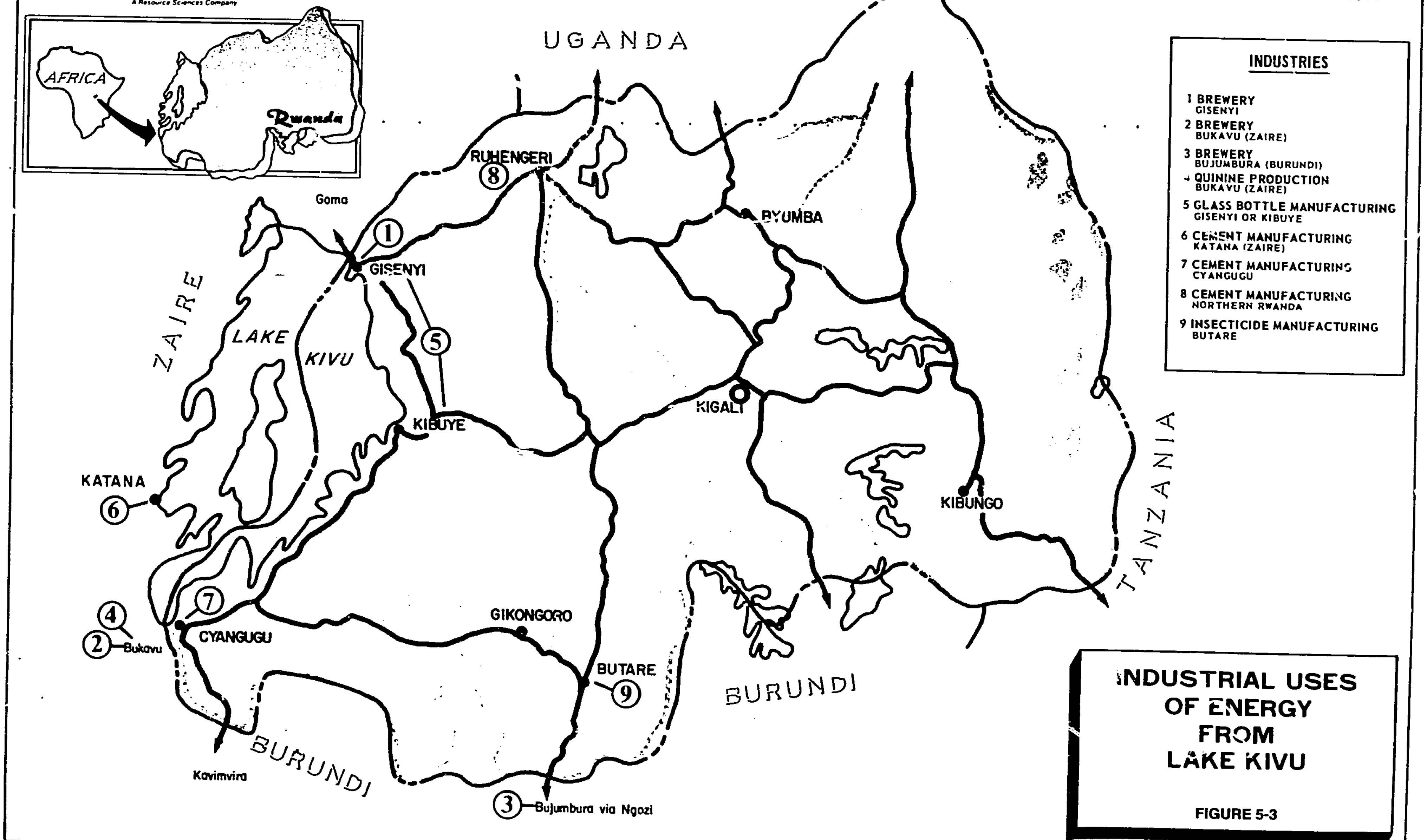
It was generally agreed by various scientific experts that the next stage of development of Lake Kivu methane production should consist of a plant of at least ten times the size of the existing pilot plant at Gisenyi.

As discussed earlier, at least one intermediate-scale plant needs to be built to produce methanol because of its universal use as a blend for imported gasoline and subsitute for imported fuels whose costs are rapidly escalating and supplies diminishing, and since it could be used for domestic lighting and cooking, thus reducing the need for burning diminishing wood supplies. Methanol could easily be dis-

TABLE 5-5

POSSIBLE USES
OF ENERGY
FROM LAKE KIVU

INDUSTRY	LOCATION	ENERGY REQUIREMENT (Million BTU's/Day)
Brewery	Gisenyi	350
Brewery	Bukavu (Zaire)	350
Brewery	Bujumbura (Buvandi)	420
Quinine Production	Bukavu (Zaire)	100
Glass Bottle Mfg.	Gisenyi or Kibuye	300
Ceramic Mfg. (Bricks, Tile, Earthenware)	Various	120
Cement Mfg.	Katana (Zaire)	2,000
Tea Drying	Various	350
Cement Mfg.	Cyangugu	1,700
Cement Mfg.	Northern Rwanda	Unknown
Insecticide Mfg.	Butare	Unknown
Food Processing (Tomatoes, Fruit, Fish, Meat, Coffee)	Various	920
Various uses as Replacement of Fuels for Automobiles and Domestic Cooking. (First Stage Use Only - Future Use Would Be Greater)	Various	2,500



INDUSTRIAL USES OF ENERGY FROM LAKE KIVU

FIGURE 5-3

tributed throughout Rwanda by utilizing existing trucking companies which include: Rwanda Links, Trafipvo, Transrwanda, Kigali Transit, Agence Maritime Internationale, Transintra and STIR. Methanol could also be moved on Lake Kivu to various points by two shipping companies presently in operation.

5.4 Gas Reserves Ownership

Lake Kivu is bordered on the west by Zaire and on the east by Rwanda. The resources in the lake (water, fish, gas, etc.) are jointly owned by both countries, and, therefore, the question of gas rights must be addressed. Basically, the question is one of allocation of present reserves and/or gas credit issuance to the nation not withdrawing gas resources.

If the gas reserves were of a finite quantity, the problem of resource allocation would be quite simple--each nation would share equally in the reserve. Each country would be allocated a given amount of the reserve, or one nation could allow the other to utilize its reserves under a mutual agreement (trade, sell, etc.). The gas reserves in Lake Kivu do not fall within this type of allocation situation, for, unlike the finite oil or gas reserves of geologic origin, the gas reserves in Lake Kivu are a renewable resource. That is, the gas is being produced/restored continuously in the lake. Furthermore, at the present time, data indicates that the gas is being naturally lost from the lake at approximately the rate at which it is being generated. This means that gas could be removed from the lake without affecting the quantity of the total reserves.

Studies recommended for the intermediate-phase gas production investigations will define quantity of gas removed, rate of resource renewal and overall effect on the total gas reserves. The intermediate-phase program will ascertain net results of gas removal and quantify actual and potential changes in the total reserves. In addition, the renewal rate can be modeled to allow estimation of removal based on the renewal without changing the total reserves.

It is expected that the reserves could afford tapping significant quantities of gas from them with little or no effect on total gas reserve quantity; intermediate-phase studies will assess this question. If this is indeed the case, there would be no need to develop a system of gas credits relative to gas removal. A system of gas credit allocation could be established if it were determined that the total reserves in the lake were being depleted by gas removal.

Studies suggested for the intermediate-phase investigations would identify renewal and removal rates and quantify changes in total gas reserves. If reserve depletion is the case, then Rwanda could provide reserve allocation credits to Zaire equal to the amount of the depletion taking place in the reserves. This would safeguard the portion of the reserves that are owned by Zaire. Zaire could elect to sell, trade or share its reserve allocation with Rwanda if it so desired or to construct its own methane plant on Lake Kivu. Under this reserve allocation arrangement, neither Rwanda nor Zaire could remove more than its rightful share of the methane reserves.

6.0 INTERMEDIATE PHASE DEVELOPMENT, FINANCE AND PLANNING

This study has shown that it would be extremely beneficial for Rwanda to develop the methane energy resource of Lake Kivu at the earliest opportunity. Prior to full-scale production, a plant of large enough capacity must be built and operated to allow the lake to be studied under dynamic conditions to gather operating data, determine gas reserves, and methane renewal rate, and to observe the effect of gas exploitation on lake stratification and the lake environment in general. In Sections 4 and 5 of this report, it has been shown that a methanol plant on Lake Kivu with a capacity of up to 95 metric tons per day is economically viable.

In the planning and design of the intermediate-scale plant, it is essential to assess the feasibility of full-scale gas removal from Lake Kivu. This information will be vital to the long-term use of the gas resources in the lake. Information gained from the intermediate-phase program will add to the data previously collected, build upon it and provide the needed data to develop sound conclusions regarding the feasibility of full-scale gas production. Numerous technical questions should be addressed during the planning, design, construction and operation of the intermediate-scale plant.

In order for Rwanda to develop the energy resource of Lake Kivu in a timely manner, the finance and planning stage of the intermediate-phase development program should begin immediately. The following scope of work for the finance and planning stage is recommended. It should be pointed out that the scope of work presented here represents only an abbreviated summary of a recommended study.

6.1 Project Management

Effective project management is the key to quality performance on any project. The project manager must have technical strengths as well as a demonstrated ability to organize and manage multidisciplinary teams of professionals in complex programs. Specific responsibilities of the project manager include:

- Development of policies and procedures consistent with the objectives of the project, and direction and supervision in the application of such policies and procedures to the performance of the project.

- Coordination of the activities of the key staff members, special consultants and organizational components to assure efficient and effective performance on schedule.

- Monitoring activities of the project organization and implementing such measures as necessary to assure that costs are properly controlled and that the client/sponsor is properly informed of all project activities.

- Continuous review of the project activities and implementation of adjustments to work activities which may appear appropriate.

- Supervision of immediate subordinates in performance of assigned functions to assure that portions and details of the work conform with the contract and technical plan.

- o Organization and presentation of material required by client/sponsor for progress reports, and formal and informal reviews and briefing as required during the performance of the contract.

The project team approach should be utilized to provide optimum efficiency and effectiveness in fulfilling project goals. The project team must be staffed by specialized individuals whose expertise, training, and experience are most applicable. Communication among project team members would be coordinated by the project manager, who will direct and supervise performance of the contract. In addition to technical and administrative supervision of the work, the project manager will be responsible for maintaining liaison with the client/sponsor and its technical staff.

Where highly specialized expertise such as intricate knowledge of local conditions and processes is required, competent research organizations and consultants should be retained.

With this approach, graphically depicted in the Project Management System Chart and a detailed PERT network, the client is assured direct access to the project team; flexibility for encompassing project changes; effective application of pertinent talent; effective cost control; and intimate knowledge of technical, environmental, and political conditions in the immediate vicinity of the project.

The overall management responsibility of the project should be determined at an early stage so that all future work will flow smoothly.

6.2 Market Identification

Potential purchasers and users of energy from Lake Kivu need to be identified. These potential users should be contacted to obtain conditional commitments or contracts. Any conditional commitments or contracts obtained should be in sufficient form and character to support project financing.

6.3 Transportation Evaluation

Potential common carriers to distribute the methanol from the Lake Kivu plant need to be identified. These carriers will need to be contacted to obtain conditional commitments or contracts. Potential common carrier arrangements will need to be evaluated to determine the optimum efficient means of transportation of the product from Lake Kivu to the user.

6.4 Preliminary Plant Design

A preliminary design of the intermediate-scale plant must be developed to prove technical feasibility and to provide a basis to estimate cost of construction. This design stage will include site selection and coordination of design with the environmental study which will be needed.

6.5 Environmental Study

An environmental study must be performed during intermediate-scale plant design and operation. The data obtained by the environmental study will aid in making various design choices to help protect the physical and biological integrity of the lake.

6.6 Estimate Plant Costs

Definitive estimates of both capital and operating costs need to be made to support project financing. Delivery time of major equipment and the cost of transportation to Rwanda should be carefully evaluated.

6.7 Financial Report

A detailed report showing the data, information and results obtained from the completion of the above-described scope of work should be made and presented in sufficient form and character to support project financing.

6.8 Determination of Financial Resources

A complete investigation should be made of all financial resources, both public and private, that might be utilized to finance the project. Detailed presentations should be made to various individuals and groups illustrating the merit and feasibility of the project so that necessary financing can be obtained.

6.9 Project Implementation

After project financing is obtained, the project should be implemented at the earliest opportunity due to the rapid rate of petroleum cost escalation, as well as increasing material, labor and transportation costs. Project implementation should include final design, construction and plant start-up.

An engineering company with a broad multidisciplinary world-wide operating capability, should be utilized to provide management and engineering services to the government of Rwanda and others who might sponsor this project.

GLOSSARY

Abiogenic - Created or produced from non-living processes.

Abiotic - Referring to the absence of living organisms.

Aerobic respiration - A metabolic function of living organisms requiring the presence of oxygen.

Anaerobic respiration - The respiration of living organisms that requires the presence of certain substances other than oxygen.

Aquatic biota - All of the living organisms within an aquatic system.

Balance of payments - A summary of the international transactions of a country or region over a period of time including commodity and service transactions, capital transactions, and gold movements.

Benthic substrate - That portion of the lake bottom which supports the growth of bottom-dwelling organisms.

Biogenic - Essential to the maintenance of life. Produced by actions of living organisms.

Btu - British thermal unit. The quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit at or near 39.2°F.

°C - Degrees centigrade. The metric system of temperature measurement in which the interval between the freezing point and the boiling point of water is divided into 100 degrees with 0° representing the freezing point and 100° the boiling point. °C = (°F - 32)5/9.

Chemocline - A strata of steep salinity gradient in a permanently stratified lake that separates two layers of unequal density.

Chemolithotrophic - The synthesizing of organic meterials using chemical energy obtained from the oxidation of inorganic compounds.

Chemoorganotrophic - The synthesizing of organic materials using chemical energy derived from the oxidation or fermentation of organic compounds.

Chemotrophic - Synthesizing organic materials using energy derived from inorganic molecules.

Conductivity - An indirect measure of the concentration of major ions within a solution.

Density - The mass of a substance per unit volume.

Dynamic conditions - Conditions marked by continuous, usually productive activity or change.

Epilimnion - The upper-most (surface) layer of water in a stratified lake.

Entrophication - The aging process of a lake in which there is a build up of nutrients and a corresponding decrease in available oxygen.

°F - Degrees Fahrenheit. A scale of temperature measurement in which the boiling point of water is 212 degrees above the zero of the scale, the freezing point of water is 32 degrees above zero. °F = (°C)9/5 + 32.

Fauna - The animal life of a given area.

Fermentation - Anaerobic production of alcohol, lactic acid, or some similar compound from carbohydrates via the glycolytic pathway.

Flora - The plant life of a given area.

Foot - A unit of length equal to 1/3 yard and comprising 12 inches. One foot = .30 meter.

Gas-water ratio - The proportion of gas in a gas-water mixture.

Hydrostatic pressure - The pressure exerted by a motionless column of water.

Hypolimnion - The bottom-most layer of water in a stratified lake.

Inorganic - Not based on carbon or living, organic processes.

In situ - In the natural or original position.

Kilocalorie - The quantity of heat required to raise the temperature of 1 kilogram of water 1°C.

Kilometer - A unit of length equivalent to 1000 meters. One kilometer = 0.621 mile.

Labeled (carbon) - A radioactive isotope of carbon whose presence and distribution can be monitored.

Marine - Of or relating to the ocean or a highly saline aquatic system.

Meter - The standard metric unit of length equivalent to 39.37 inches or 3.28 feet.

Methane - CH_4, a colorless, odorless, flammable gas which forms about 90 percent of natural gas.

Methane-water ratio - The proportion of methane gas in a methane gas-water mixture.

Methanol - A clean-burning hydrocarbon fuel of low molecular weight.

Metric ton - The metric unit of mass equivalent to one million grams or approximately 1.1 U.S. tons.

Mile - The standard U.S. unit of length equivalent to 5280 feet or 1.609 kilometers.

Mcf - One thousand cubic feet.

MMcf - One million cubic feet.

Multidisciplinary - Involving more than one discipline or area of study or concern.

Normal cubic meter - The standard reference of metric volume equivalent to 35.315 cubic feet.

Metalimnion - The stratum of water separating the epilimnion and hypolimnion and characterized by a steep temperature or chemical gradient.

Organic - Containing carbon or derived from living, organic processes.

Overturn - When the water in the upper stratum of a lake increases in density and sinks, displacing the lower strata, which rise to the top, or mixes throughout the water column.

Oxidation - Energy releasing process involving removal of electrons from a substance; in biological system, generally the removal of hydrogen (or sometimes the addition of oxygen).

Phototrophic - Synthesizing organic material using light as the source of energy.

Phytoplankton - Small plant organisms (algae) floating or drifting in a body of water.

Plankton - Small organisms floating or drifting in a body of water.

Primary productivity - Total quantity (biomass) of photosynthetic plankton (phytoplankton) produced per unit time in a specified habitat.

Raw gas - A gas whose principal component is contaminated with other gaseous fractions prior to refining.

Salinity - Refers to the presence of salts of the alkali metals--calcium, magnesium, sodium and potassium.

Secondary productivity - Total quantity of animal protoplasm produced per unit time in a specified habitat.

Standard cubic foot - Measured at one atmosphere (14.7 pounds per square inch) and 60°F (15.5°C).

Standard cubic meter - Measured at one atmosphere (14.7 pounds per square inch) and 32°F (0°C).

Stratification - The state of being in two or more layers.

Sublacustrine - Below a large body of water, such as underneath a lake bed.

Temperature inversion - A reversal of the normal temperature gradient of a lake; i.e., warmer water lying below cooler water.

Thermocatalytic - Increase in the rate of a chemical reaction due to the addition of heat.

Thermocline - A strata of steep temperature gradient that separates two layers of water of unequal temperature and density.

Trace elements - Elements present in very small amounts.

Trophic level - Any of the feeding levels through which the passage of energy through an ecosystem proceeds; examples are photosynthetic plants, herbivorous animals, and micro-organisms of decay.

Tuff beds - A layer or area of rock composed of the finer kinds of volcanic material usually fused together by heat.

Zooplankton - Small animal organisms floating or drifting near the surface of a body of water.

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