REPUBLIC OF RWANDA

MINISTRY OF ENERGY, WATER AND NATURAL RESOURCES
Unit for the Promotion and Exploitation of Lake Kivu Gas

LAKE KIVU GAS DEVELOPMENT AND PROMOTIONAL RELATED ISSUES

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CONTENTS

TABLES

FIGURES

LEGEND

BTU: British thermal unit;
MMBTU: Million British thermal units
Sm3: standard cubic meter
TOE: Ton oil equivalent
SOCIGAZ: Sociéte de contrôle de l'exploitation du gaz méthane du lac Kivu
EIRR: Economic internal rate of return
KWh: kilo Watt hour
MW: Mega Watt
GWh: Giga Watt hour
FRW: Rwandan Franc

1. INTRODUCTION

The objective of this report is to assist the Government of Rwnada in evaluating the development and exploitation options of the methane gas resources of the Lake Kivu and their promotion. The existing studies were reviewed and the various options proposed have been analyzed with a view to select an appropriate strategy for the development of the methane gas consistent with the country's energy needs, and the specificity of Lake Kivu. The report will also develop the basic elements needed to produce a promotional note to encourage the participation of the private sector in development of the gas.

The main intervention for this assessment took place in June 2000 to discuss with the concerned Governmental Units the detailed scope of work, consult all the exiting documents and studies and visit the methane production pilot plant installed at cape Rubona near the town of Gisenyi. A second mission was made in July to complete the review and analysis and to deliver a workshop on the development of the gas for members of the Government and potential investors from the private sector.

Rwanda faces serious energy problems principally due to the total lack of traditional petroleum resources. Being a landlocked country, all liquid fuel products have to be imported at high cost using road tankers. Most of the population use wood and agricultural by-products for their basic energy needs making fuel wood increasingly scares and creating serious deforestation problems all over the country. Rwanda has a significant potential for generation of electricity from hydro in numerous, steep fast flowing rivers and streams. However, hydro sites are generally costly to develop because of the small capacity and the difficult topography. Present domestic grid connected generating facilities include four hydroelectric plants with a total installed capacity of 26.5 MW.

Together with the Republic of Congo, Rwanda has a unique energy resource in the form of methane gas dissolved in the deep waters of Lake Kivu, which straddles the borders of the two countries. The amount of methane in place is estimated at about 59 billion cubic meters of which 29 billion cubic meters (29 million TOE) are believed to be economically recoverable. A small methane extraction "pilot" unit was installed in 1963 to supply some 8000 cubic meters of methane per day to the Brawirla Brewery and has clearly demonstrated the technical and economical feasibility of methane exploitation at a larger scale.

2. CHARACTERISTICS OF LAKE KIVU WATERS

Lake Kivu is part of the western branch of the rift valley formed along the junction of the African and Somalian shields and is believed to have formed following the elevation of the Virunga volcanic arc some 500 000 years ago. The lake straddles boarders between Rwanda and the Republic of Congo and covers a surface area of 2400 km^2, more or less equally distributed between the two countries. It comprises two deep and steep fluvial valleys, separated by Ijwi Island. The water depth in the main basins exceeds 450 meters, refer Fig. (1).

Like in most lakes, waters of Lake Kivu are represented by a succession of horizontal layers having different physical and chemical properties, but properties remain constant within the same layer. The layering "stratification" of the water in Lake Kivu was discovered in the 1930s and is clearly identified from measurements of water properties conducted over the past few decades on vertical profiles at numerous locations on the Lake. Comprehensive measurements and analyses on Lake's stratification were carried out by K. Tietze in 1977, and confirmed previous measurements conducted by other works (D.M Schmitz, D. Van Den Ben, R. Kiss, E. Degens, H. W. Jannash) since the 1950s.

The above measurements have also confirmed the remarkable stability of the physico-chemical characteristics of the Lake, in spite of extraction of gas since 1963. These measurements have also shown:

- Analogous evolution of temperature and conductivity with depth. The conductivity of water is directly related to the content of dissolved mineral salts;
- The alkaline nature of surface waters where the pH is close to 9, but this pH decreases rapidly with depth and stabilizes around 7 at a depth of 90 meters, then water becomes slightly acid at greater depths essentially due to the higher volumes of dissolved carbon dioxide (CO_2) and hydrogen sulfide (H_2S);
- Waters below the depth of 90 meters are deprived of oxygen and are stagnant;
- Sharp increase of temperature and dissolved mineral salts below a depth of 270 meters. This increase is accompanied by exceptionally high content of dissolved carbon dioxide and methane gas (CH_4) in the water. This sharp increase at the depth of 270 meters marks the top of the main water stratification in the Lake; and
- The sulfur is present in the form of dissolved hydrogen sulfide at depths greater than 90 meters.

The higher water temperatures below the depth of 270 meters are likely to result from the discharge of hydro-thermal hot springs into the bottom of the Lake, and the influx of heat from volcanic intrusions in the underlying strata. The higher concentrations of mineral salts in the water below 270 m make the water at the bottom denser than that at the top, in spite of the higher temperature and dissolved gas content.

The remarkable stability of water properties and stratification indicate that mixing of Lake waters, through vertical convection currents or diffusion, to be insignificant. Further, the water currents created by the incoming or out-flowing water from the lake do not seem to affect the stability of water stratification, at least below the depth of 270 meters. The stagnant conditions in the deeper parts of the lake, the high concentration of mineral salts in the water and high pressures and temperature are favorable factors for the generation of methane and the absorption of substantial volumes of carbon dioxide and methane into the water.

3. ORIGIN AND GENERATION OF METHANE

The process leading to the formation and accumulation of methane and carbon dioxide in the deeper waters of Lake Kivu's is not fully known. Few hypotheses have been advanced on the processes leading to the formation and the enrichment of the deep water in methane gas and carbon dioxide. Methane gas is believed to form in the Lake from a combination of geological and biological processes. Carbon dioxide of volcanic origin is reduced to methane by the anaerobic bacteria, which proliferate in the stagnant deep waters of the Lake. The same bacteria cause also the decomposition and fermentation of the organic material accumulating in the bottom sediment, leading to the formation of carbon dioxide and methane. The latter is similar to the process leading to the formation of oil and gas in sedimentary rocks. Two thirds of the methane generated is believed to come from the reduction of volcanic carbon dioxide and the remaining fraction is from the fermentation of organic material. It is estimated also that some 100 to 150 million cubic meters of methane are generated annually in the lake.

4. METHANE RESERVES

The total volume of methane gas contained in the waters of Lake Kivu is estimated from:

- The variations of the *methane water ratio (MWR)* with depth. This is expressed as the standard volume of methane per one unit volume of water at lake conditions (pressure and temperature); and

- The variations of the volume of water in the Lake with depth.

The MWR is determined from direct measurements on the Lake. Several campaigns of measurements have been conducted since the 1950s. Those presented by K Tietze, refer Fig. (2) are considered to be the most reliable. The variations of water volumes with depth are deduced from bathymetric surveys. Two of such surveys were conducted on the Lake, by Capart in 1960 and Lahmeyer in 1998, and the results obtained are consistent.

The variations with depth of the volumes of gas dissolved in the water are obtained from simple multiplication of the profiles representing the variation of gas water ratio, by the variation of water volumes with depth, Fig. (3). The resulting profile is then numerically integrated (summed-up) to derive the total volume of gas in the lake "*gas in place"*.

The total volumes of methane in place, derived from the above procedure, are 63 and 55 billion standard cubic meters, based on the bathymetry of Capart and Lahmeyer respectively. The most likely volume of methane in place would then be the average of the above figures, hence 59 billion standard cubic meters. The fraction of methane in place, which can be economically recovered, in other words *methane reserves*, is then estimated knowing:

- The fraction of Lake's water which can be economically processed to recover the methane gas; and
- The fraction of the total gas in solution, which can be extracted "liberated" from the water using a given configuration and conditions of the separation and processing facilities.

The fraction of water that can be economically processed to recover the methane is the fraction situated below the depth of 270 meters where the highest concentrations of methane are encountered. This fraction of water represents about 23% of the total volume of water in the Lake and accounts approximately for 65% of the total volume of methane in place.

Fig. (2) Evolution of Water Gas Ratio

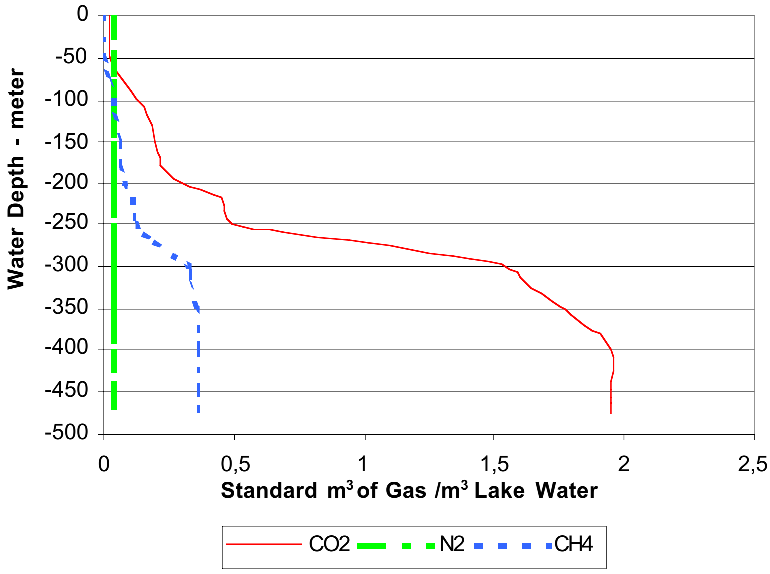
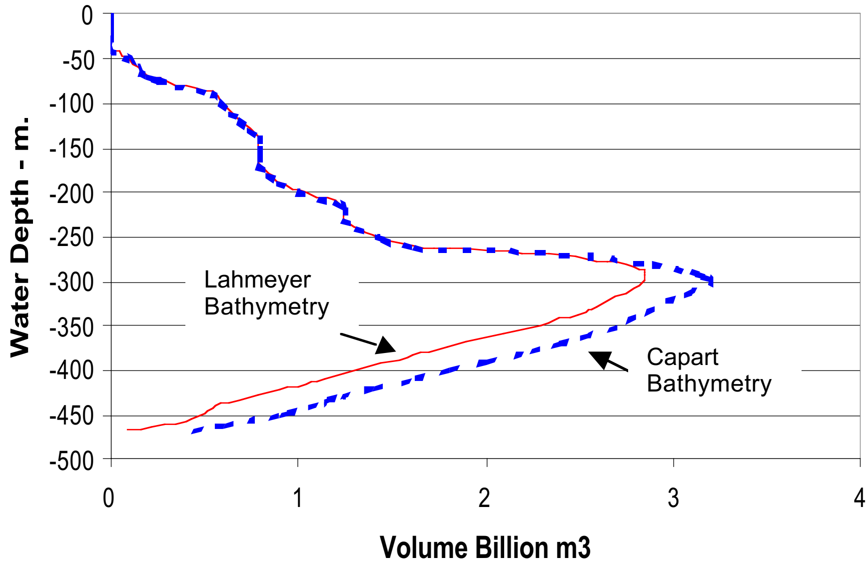


Fig. (3) Variations of the Volume of Methane



Regarding the efficiency of gas extraction, trials conducted in 1995 at Cap Rubona, under real project conditions, refer table (1) below, indicated that some 75% of the initial methane content of the water would be extracted.

Table (1): Results of gas extraction on site at Cap Rubona.

Separation depth m.	*Pressure bar*	*Crude Gas S. vol/vol*	*Methane S. vol/vol*	*Gas Fraction %*			
				CO2	*CH4*	*N2*	*H2S*
0.5	*0.90*	*1.150*	*0.261*	*76.57*	*22.66*	*0.67*	*0.10*
5.0	*1.35*	*0.920*	*0.255*	*71.37*	*27.70*	*0.84*	*0.09*
8.5	*1.70*	*0.760*	*0.234*	*68.24*	*30.75*	*0.94*	*0.07*
10.0	*1.85*	*0.67*	*0.227*	*64.87*	*33.85*	*1.22*	*0.06*

It follows that the ***recoverable*** reserves of methane are equal to 75% of initial volume of methane in place in the water below the depth of 270 meters, or about 29 billion standard cubic meters.

The methane reserves estimated above are proven reserves as they carry little uncertainty, because the parameters used in the estimates (methane water ratio, volume of water in the lake, and methane recovery from crude gas) are well determined. It should be noted that the amount of the above reserves, even in the absence of methane renewal in the Lake, could sustain large-scale production sufficient to satisfy the equivalent of the current hydrocarbon consumption in Rwanda for a few centuries.

5. DEVELOPMENT PROSPECTS

5.1 Present Development

The feasibility of large-scale methane exploitation from Lake Kivu is well established. The pilot plant built in 1963 at Cap Rubona on the Rwandan shore of the Lake has perfectly demonstrated the technical and commercial feasibility of gas exploitation from the Lake. To date, some 18 million standard cubic meters of methane gas have been produced. Nearly all of the gas has been used as a boiler fuel in the nearby Bralirwa brewery.

The gas production and process facilities installed at Cap Rubona plant are relatively simple. Water from the methane rich zone is brought to the surface through two large pipes, "*the water production string*". As the water rises in the production string, its pressure decreases causing progressive liberation of the gas in solution in the water. The increasing proportions of free gas bubbles as the water nears the surface in the pipe induce a process of "*gas-lift*" giving rise to a naturally continuous eruptive production of water from the deeper parts of the Lake to the surface. The liberated gas and the partially degassed water are passed through a water-gas separator, operating at a pressure slightly higher than the atmospheric pressure, where more gas is liberated and separated from the water.

The gas separated from the water, "*crude gas*", is essentially a mixture of about 70% carbon dioxide (CO_2) and 30% methane (CH_4). This crude gas is then put through a series of gas washing "*scrubbing*" tanks where water from shallow depth in the Lake, having relatively little amount of gas in solution, is circulated. Coming in contact with the crude gas, the circulating water dissolves and removes the major part of the carbon dioxide fraction from the crude gas. The resulting gas at the outlet of the scrubbing tanks has approximately 80% methane, 18% carbon dioxide and 2% of nitrogen. This gas “sales gas” is then dried, compressed and evacuated through a 3” flow line to the brewery to be used as fuel. The degassed *residual water* from the water-gas separator is mixed with the scrubbing tank water and disposed of into the Lake below the surface. A schematic presentation of the process described above is shown in Fig. (4).

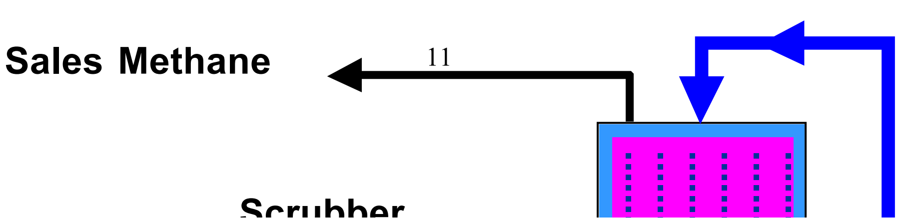
5.2 Further Development

Rwanda has been considering an expansion of the production capacity of methane gas from the Lake, and has taken the necessary steps to encourage the intervention of private investment in the sector. Larger scale development of the gas may be done through the installation of new production and process facilities to supply, in addition to the brewery, other gas fueled utilities.

In view of larger scale exploitation of the methane gas, a number of studies have been made to address and optimize the technical, commercial and environmental issues. These studies were justified seen the uniqueness of the Lake Kivu gas resource and the lack of experience on comparable projects elsewhere. Naturally, the approach in all the above work was to draw on the experience gained from the Cap Rubona pilot plant. However, the majority of these studies, with the exception of the one carried out by Tractionel Electrobel Engineering, in 1984, relative to the expansion of the unit at Cap Rubona, have never gone beyond the preliminary stage.

The choice of technology for methane extraction will determine the development and operating costs, hence the gas supply cost. The technology currently in operation at Cap Rubona and all the variations proposed in the various studies are simple, proved and, in all cases, are far less complex than the technologies used by the oil and natural gas industry. This is because the gas produced from the waters of Lake Kivu is a low pressure and temperature gas.

FIG. (4) LAKE KIVU
PRINCIPLES OF GAS EXTRACTION



The current pilot project at Cap Rubona has provided valuable experience in resolving and addressing a number of technical and environmental issues, which would be associated with large-scale exploitation of the methane. Some of these issues are:

- Choice of the materials used to fabricate the production string and gas processing equipment, to alleviate corrosion problems caused by the presence of carbon dioxide (CO_2) and hydrogen sulfide (H_2S);
- Erosion of the pipes composing the water production string caused by vibration and friction with hard soil along the route of pipes;
- Optimization of gas separation and methane recovery;
- Water production and disposal volumes per module; and
- The depth of water intake point and the safe disposal of residual and carbon dioxide scrubbing water into the Lake, in a way compatible with the Lake stability and the environments.

The major constraint in the development and exploitation of methane from the Lake is the lifting, handling and recycling back to the Lake massive volumes of water in order to produce comparably modest quantities of methane. Consequetly, the maximum size of facilities and equipment which can be installed determine the upper limit of the water volumes which can be degased and processed per production unit. Therefore, to achieve a relatively high methane production level the development has to be modular. The quantities of water which can be handled through a single module govern the whole concept of design, and thus the costs and economics of gas development and exploitation.

5.3 Development Alternatives

The above studies have examined several alternatives for the location of facilities, lifting the water from depth, separating and processing of the gas. These alternatives are:

On-shore installation similar to the unit installed at Cap Rubona. The advantages of this system are:

- The technology used is perfectly proved; and
- Simplicity of facilities and easy accessibility.

The main drawbacks are:

- The need for suitable sites on-shore similar to Cap Rubona to enable reaching the water intake point at a depth of 300 - 320 meters with a water production string of less than 1200 meters in length. There are only few such sites on the Rwandan shore compatible with this requirement;
- Erosion and wear of the pipes as a result of vibration and friction with hard soil along the Lake slopes; and
- The need for relatively voluminous earth moving and civil works.

Offshore development consisting of small anchored floating platforms to support the vertical water production string and the gas process facilities.The separator and the scrubbing tanks may be placed beneath the platform, fig. (5). The system comprises two pressurized carbon dioxide scrubbing cycles using a pump to return degassed water to the separator to improve the gas recovery efficiency. The Gathering and monitoring facilities are installed on a central floating platform. The central platform houses also office space and accommodation for a minimum number of technicians and staff. The methane gas is then evacuated to shore via a submarine pipeline.

The main advantages of the offshore development are:

- The system provides total flexibility for the choice of water intake sites on the Lake;
- Easier installation and less problems of erosion and wear of the water production string; and
- Better distribution of water intake points to ensure fewer disturbances to Lake stability.

The offshore alternative has the following main drawbacks:

- Electrical power supply to the installations requires either the installation of a power generating unit on the platform, which requires extra space, or external power supply via a sub-sea cable. The latter case, in particular, represents significant additional investment cost for power transmission;
- Similarly, either crude gas or methane gas evacuation to shore will require the installation of a submarine flow-line which has to be suspended some 25 meters below the water surface, as it would be difficult to lay such a pipe on the Lake bed owing to the relatively high water depth and Lake topography;
- Requirement for additional compression to circulate the gas, which translates into higher investment and operating costs.; and
- Requirement for a boat and a barge for the transportation of supplies and personnel for intervention on the offshore installation.

Semi-offshore installations comprising an anchored floating platform connected to shore by a floating bridge. The platform will support all the gas processing facilities, which comprise a gas separator mounted on multi-stage carbon dioxide scrubbing tank, in a vertical column configuration, of about 25 meters high, to process the gas to 80% methane content. The separator and the scrubbing tanks are placed beneath the platform, fig. (5). The gas cycling compressor and other utilities will be installed on the platform deck.

The advantages of the semi-offshore installations system are:

- The system allows the construction of a relatively compact platform as all the gas processing facilities are installed in the water beneath the platform;
- Easy access to the platform, which eliminates the need for personnel transport, laying a submarine flow-line to evacuate the gas, and underwater cables for power transmission. Such facilities will be laid along the bridge connecting the platform to shore;
- The possibility to optimize the carbon dioxide scrubbing tank pressure by adjusting its depth below the water surface under the platform; and
- The system allows to attain the water intake depth with a shorter water lift column and therefore eliminates partially the site constraint associated with on-shore installation;
- The system could presents also a cost advantage over the offshore and possibly the onshore installation. However, investment costs increase the further the platform is located from the shore

Like in the offshore case, gas scrubbing is done at a higher pressure and, there would be a requirement for additional compression to circulate the crude gas into the scrubbing tank for the removal of carbon dioxide. On the other hand, scrubbing under higher pressure would minimize the volume of surface water used for the removal of CO_2, hence smaller volumes of water to handle and disposed back into the Lake.

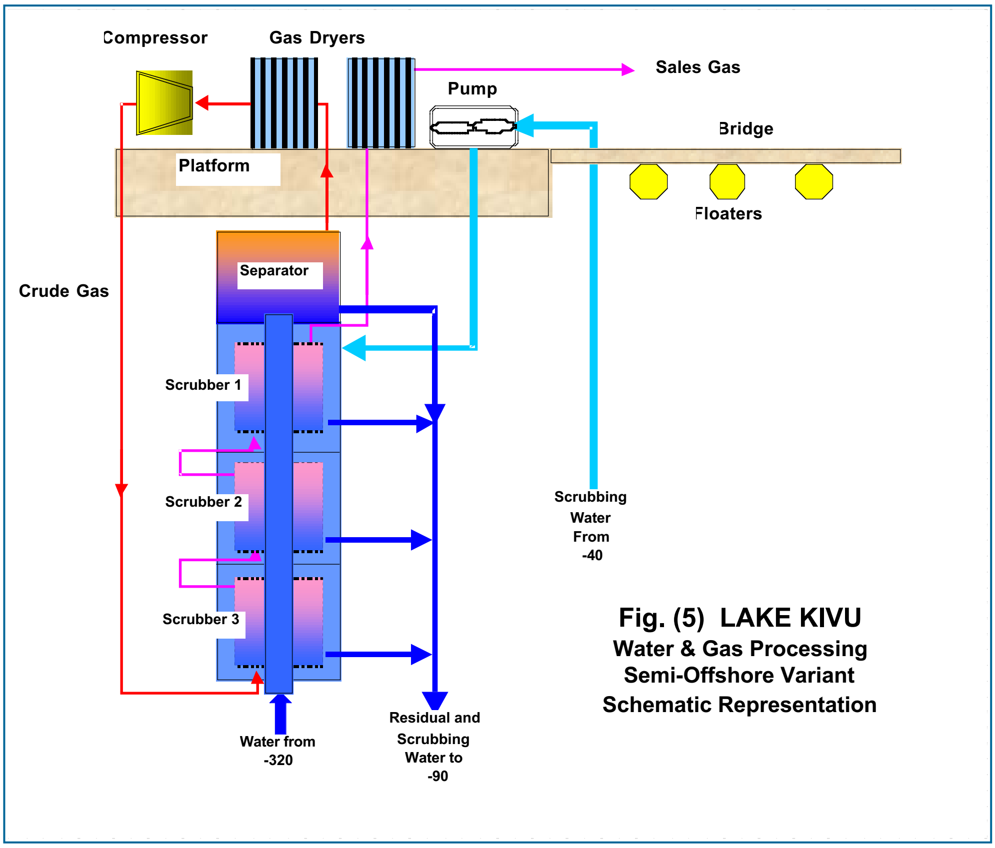


Fig. (5) LAKE KIVU
Water & Gas Processing
Semi-Offshore Variant
Schematic Representation

5.4 Water and Gas Process Optimization

Technip of France conducted, in 1988, a process optimization study relative to gas extraction from the deep waters of the Lake and the scrubbing of carbon dioxide. This was taken-up by Tecnitas in 1995, but the principle remained the same. Different techniques for the lifting of deep water and processing conditions were investigated. These included:

- Auto lift of the water induced by the liberation of gas in the water lift string;
- Artificial pumping; and
- Separation of gas and scrubbing carbon dioxide under different pressures.

The scheme which was finally recommended, consisted of:

- Auto lift of the deep water. Artificial pumping was rejected because of uncertainties relative to the efficiency of pump under the exploitation conditions and the large additional investment required:
- Separation of gas from water under a moderate pressure of 0.5 to 1 bar; and
- Scrubbing CO_2 from the crude gas, using three stages, installed in a vertical column arrangement, and counter-current flow under an average pressure of about 2 bars.

The recommended configuration is particularly adapted for the offshore and semi-offshore installation variants described above. The gas separation-scrubbing column will be installed beneath the platform, refer Fig. (5).

Regarding materials, the study has recommended the use of thermo-hardening resins enforced with glass fiber. This type of material has the required mechanical properties and is very resistant to corrosion and local conditions of the Lake. Further, The material may be used for the fabrication of large diameter pipes for the water production and disposal pipes as well as for the fabrication of separator and scrubbing tanks having the required large diameters.

6. POTENTIAL UTILIZATION OF GAS

In general, the bulk uses of gas in the world are in:

- Power and industrial plants where gas displaces fuel oil;
- Industries as a feedstock for processing the gas into derivatives such as methanol, urea etc.; and
- Residential sector, in particular, of cold countries of the Northern Hemisphere.

The utilization of methane gas as fuel or feedstock in the bordering countries to Lake Kivu has been investigated with relative details. Technip, in their study of 1988 presented an inventory of gas utilization in most sectors except, the power sector. In 1995, Tecnitas revised part of the work conducted by Technip and investigated briefly the economic feasibility of using the methane gas in power generation. The utilization's investigated are briefly discussed below:

- ***Industrial Sector***: Gas utilization in the industrial sector is represented by the Bralirwa brewery currently supplied by the Cap Rubona pilot plant. Bralirwa brewery is situated at some 3 km from the methane production unit at Cap Rubona, and the gas transmission costs by pipeline are insignificant. The other main potential gas user in Rwanda is the Cimerwa cement plant situated on the southern extremity of the Lake at about 20 km to the south of Cyangugu. The feasibility of laying a ring pipeline infrastructure around the Lake to supply gas to potential consumers in Rwanda and the Republic of Congo was also analyzed.

- ***Household and Residential Sectors***: Utilization of methane as fuel in the form of compressed natural gas (CNG) for domestic needs, essentially cooking, presents a number of technical and commercial difficulties. While the utilization of LPG is common in the household sector, utilization of methane in the form of CNG indoors represents serious safety problems as CNG cylinders are generally conditioned at pressures in excess of 200 bars. Such pressures require that cylinders as well as piping be fabricated in special alloy metals of considerable thickness to withstand pressure and resist corrosion. The compression cost and the high purchase price of gas cylinders and maintenance cost would triple the cost of gas supply at the production plant. For the above reasons, and taking into account the distribution cost, utilization of compressed methane in the household sector would not be feasible.

  Generally, the use of methane in the residential sector requires very large investments in the distribution network and high maintenance cost. Such investment would only be justified by the high level of gas consumption, like in cold climate countries where gas is used essentially for heating. However, utilization of methane in the residential sector in Rwanda could eventually be considered for well maintained, dense residential (high fire woods and charcoal consumers) compounds provided they are located very close to the production units.

- ***Gas as a Feedstock***: Production of urea and methanol require plants of a considerable size to benefit from economies of scale, hence well established markets that can rapidly match production capacity. Furthermore, the technical sophistication and the considerable cost of such plants require highly trained working force and low cost feedstock (generally less than 5 cents per a Sm3) to make the cost of locally-produced derivatives competitive with the imports they would displace. Seen the small level of methane production, market uncertainty, and the high cost of supply of methane gas from Lake Kivu, the prospects of urea and methanol production in Rwanda would be highly uncertain.

  The above comments apply equally to the use of methane for the production of sinfully to displace imported motor fuels. Again, the capacity of the very few operating units in the world, which represents the minimum economic production scale of the industry, largely exceeds the projections of potential demand, even taking the long-term perspective. Therefore, Lake Kivu's gas would appear to have no immediate nor a prospective market in the production of sinfully.

- ***Power Generation*** potentially constitute biggest utilization for Lake Kivu methane gas. Power generation is definitely the most favorable option of gas utilization due to the following reasons:

  (a) The present confirmed unsatisfied demand for electricity is estimated at about 15 MW. Generation of such capacity would require an annual supply of methane gas of 48 million standard cubic meters. This amount of gas can be readily achieved from two gas production units each having an annual production capacity of 24 million standard cubic meters;

(b) Methane produced from the Lake will have the highest opportunity value in power generation, if electricity is produced on site. It should be noted also that the use of gas for power production would not be only the lowest-cost alternative for producing electricity, but often a pre-condition for justifying the expense of building a gas delivery system that can be utilized to deliver gas to other users at reasonable costs; and

(c) The power generated on site of the methane production may either cover local need and/ or be transmitted to other consumers using the national grid. Transmission of power through the national grid implies upgrading certain sections of the grid and/ or constructing 10 to 20 km of new transmission line to connect to the grid.

(d) Gas production / power generation platform barges can be designed and fabricated overseas, shipped in modules to Rwanda and assembled on site with a short lead time. Barges represent lower risk to investors as they have the advantage of being mobile and can be moved in the event of default

Preliminary economic analysis of methane utilization in power generation was considered in Tecnitas' study in 1995. Further, the economic and financial analyses made as part of this report confirm the viability of gas utilization in power generation and indicate that the cost of electricity produced would be competitive with power supply from potential hydro projects.

- ***Transport Sector***: Utilization compressed natural gas (CNG) as vehicle fuel was also considered. Such utilization implies the following constraints:

(a) The necessity to have gas processed to a high degree of methane content to improve its thermal efficiency and to avoid serious corrosion problems to critical parts of the engine, due to the presence of carbon dioxide, moisture and hydrogen sulfide in the gas;

(b) The need for substantial additional investments in gas compression and distribution net work, as the autonomy of vehicles running on CNG is approximately half that of vehicle using liquid fuel. Gas compression and transportation of CNG costs could be twice as much as the methane production cost;

(c) The need for relatively costly modification to vehicles. It should be noted that engines running on CNG develop 30% less power than an engine of the same size using liquid fuel. This could be a major concern in a high relief country like Rwanda.

Preliminary analysis indicated that the utilization of the methane produced from Lake Kivu in the transport sector would not be a viable option, essentially due to the relatively high supply cost of the gas and the additional investment needed for gas compression and CNG distribution.

7. PROJECT COST

Preliminary cost estimates have been made by Tractionel Electrobel Engineering in 1984 and by Technip/ Tecnitas in 1986 and 1995. These costs have been revised to account for specifications of the development recommended in this report, and to reflect current conditions of construction in the gas sector. Estimates of initial investment costs have been made for the following alternatives:

- ***Gas Production***: It is assumed that a semi-offshore methane production unit will be installed. The unit will comprise 4 modules, each having a net annual production capacity of approximately 6 million standard cubic meters of gas processed to about 80% methane content.

Table (2): Summary of initial capital cost estimates for gas and electricity production
Thousand US$

Components	Gas Production		Electricity Production	
	Million m3		GWh	
Net Annual Production	6.0	24	14.2	56.6
Site	0	0	0	0
Civil, platform and bridge	92	334	92	334
Water and gas process facilities	822	3122	822	3122
Gas drying equipment	230	656	230	656
Electro-mechanical equipment	1725	6520	2960	11460
Other equipment	115	425	165	623
Engineering	238	553	255	648
Total	**3222**	**11609**	**4524**	**16842**

- ***Electricity Production***: It is assumed that all the gas produced from the above unit will be utilized for electricity production by installing the appropriate power generation unit on the same site as the gas production unit. The design of the gas production equipment remains unchanged.

The costs are grouped by nature of equipment having the same depreciation/ amortization life. The capital investments needed for one and four gas production modules, and the appropriate power generation units are summarized in table (2) below. These cost include a 15% contingency.

It is assumed that project site is leased to the operating company for no charge. The preliminary nature of the above estimates should be emphasized, and costs will need to be revised following the primary engineering of the project.

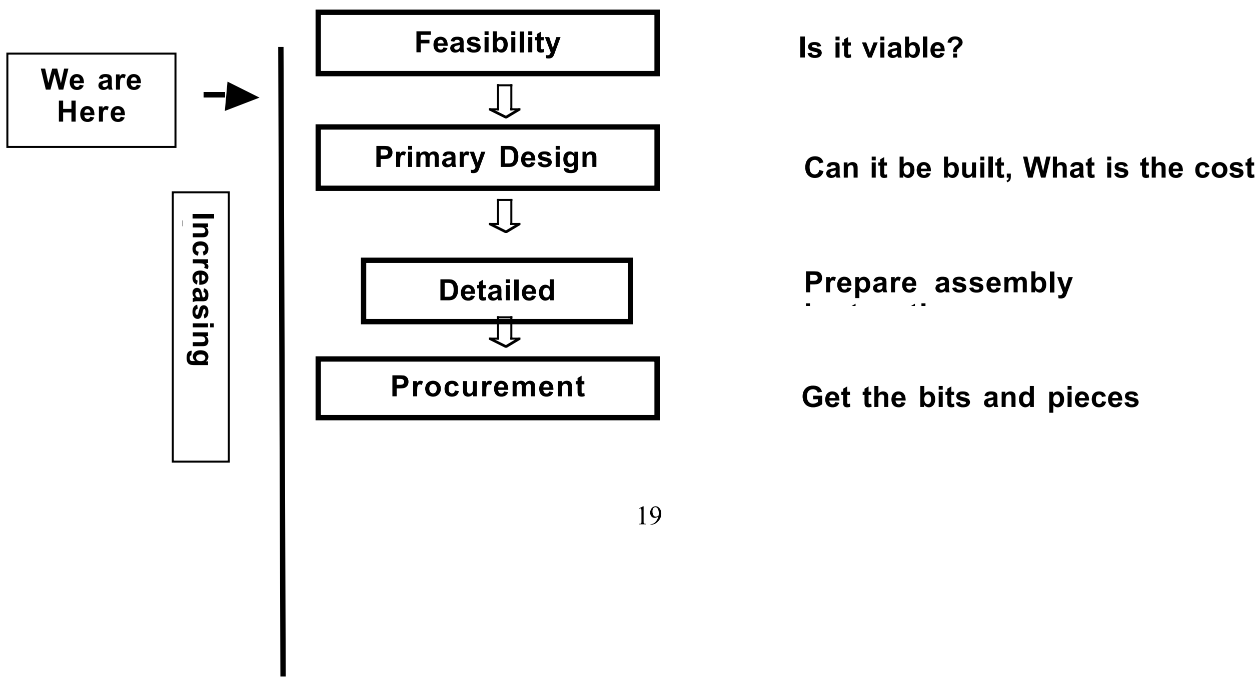
8. PROJECT SCHEDULE

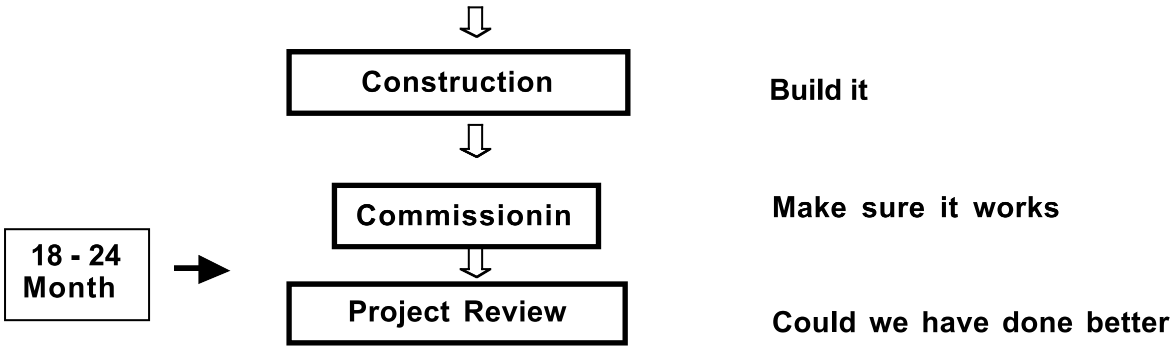
The technical and economic feasibility of gas exploitation from the Lake is well established. The options for the development are narrowed down and the preferred option has been identified as the semi-offshore scheme, on the basis of technical, economical and environmental considerations. Now, for the project to go forward, work needs to continue on the primary design to tighten cost estimates. The object of the primary design phase is to prepare a document that will provide sufficient details to give financiers confidence that the project is technically sound and commercially robust. The document is also needed to get approvals to proceed from government bodies. As most of the technical and engineering issues have been already tested at the unit installed at Cap Rubona. This stage need not be elaborated in great details. The document will also form the basis for the preparation of a tender document to contract out the project, preferably on turnkey basis.

The detailed engineering, which would be carried out by the contractor, is to initiate procurement activities and construction planning. The emphasis at the detailed stage is to achieve the appropriate design and reduce to the minimum the need for changes during subsequent stages. Under turnkey the contractor would carry out the procurement, but it would be important to ensure that the supply of spare parts is secured.

The project construction management will be responsible for delivering completed works to specification and within time and budget limits. During commissioning, the construction team will hand over the project to the operating team once the equipments have been fully tested. The project schedule is schematically shown in Fig. (6). The total time need to complete the project is expected to take from 18 to 24 months.

Fig. (6) DEVELOPMENT PHASING





9. PRICING OF GAS

Gas from Lake Kivu will be used essentially as a substitute fuel and, therefore, it must compete with the fuels it potentially can replace in the actual Rwandan setting. Such fuels will be imported petroleum products.. In order for Lake Kivu gas to be an attractive substitute fuel, it should be delivered to end-users at a cost lower than that of fuels currently used, by at least the conversion margin. Therefore, the sum of gas production and transport costs should be less than the cost of fuels on the Rwandan market, shown in Table (3).

Generally, the burner tip values for gas are derived by calculating the total cost of producing energy from another fuel, for example fuel oil, diesel oil, etc. Then from the value derived, the cost of equipment that is needed to burn the gas is subtracted to obtain the maximum amount the consumer would be prepared to pay for the gas. Transmission and distribution costs are subtracted from the burner tip value to obtain price of gas at the gate of the gas production unit.

Table (3): Cost of Petroleum Products US$/ Cubic meter

	Fuel oil	Kerosene	Diesel Oil	Gasoline
FOB Source	145	297	277	315
Transport Cost	202	113	107	107
CIF Kigali	307	410	383	422
Conversion Cost*	18	36	48	180
Gas Market Value**	0.238	0.299	0.268	0.193

Products cost communicated by the Gas Unit, Rwanda, October 2000.
* Estimated
** Estimated based on calorific equivalence of gas containing 80% methane.

Gas from Lake Kivu would have the highest value in power generation because the capital and operating costs of gas fueled plants are much lower that those of high sulfur heavy fuel oil or coal fueled plants. Gas has also a high value in the residential sector where the competing fuel is gas oil, but gas use in this sector will only be viable in Rwanda if the transmission and distribution costs are very low. This implies that the residential sector supplied is situated within few kilometers from the gas production facility.

The opportunity or market value for gas is defined as the maximum a gas supplier could charge the consumer and still remain competitive with other fuels. The principle of calculation is illustrated in Fig. (7).

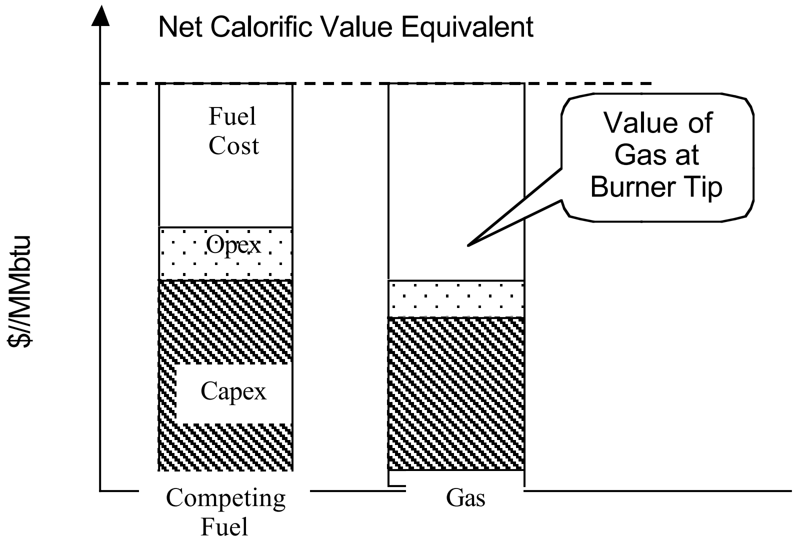


Figure (7): Principle of determining the market value for gas

The capital cost to the consumer of using the competing fuel (coal, fuel oil, diesel oil. etc.) is calculated. The cost comprises:

- The capital and operating costs of the equipment the consumer needs to burn the competing fuel; and
- The cost of computing fuel per unit of net energy produced, taking into account the efficiency of burning the fuel.

The capital and operating costs of the equipment that the consumer needs to burn the gas are subtracted from the total cost of using the competing fuel. This gives the maximum amount the consumer might potentially be willing to pay for the gas, and hence (allowing for efficiency of use) the burner tip value of gas.

10. ECONOMIC ANALYSIS AND COST OF GAS SUPPLY

The objective of the analysis is to establish the economic interest of the project and verify its financial viability to developers, taking into account the opportunity price for gas as a substitute for competing fuels, essentially petroleum products in Rwanda. It should be noted that the analysis is based on preliminary cost figures and needs to be refined once more accurate estimates become available. It is also assumed that the demand for energy in Rwanda is such that all the gas produced will be absorbed.

The economic analysis is presented in table (4a). This is a cost/ benefit in constant money, conducted over a period of 20 years, without taking into account taxes and duties.

The costs comprise:

- The initial investments, including contingencies, engineering and project administration and management;

- The additional investments required to replace the production equipment, during an exploitation period of 20 years; and

- The annual operating costs.

The economic cost of gas processed to 80% methane content and delivered at the gas production plant (having an annual capacity of 24 million Sm3) is approximately 8 cents / Sm3 ($2.83/ MMBTU), at 10% discount rate. Similarly, in the case of electricity production the cost of generated kWh, using methane gas as fuel, would be $0.049. These costs do not take into account any taxes, duties or royalties, which may be levied on gas production.