ENERGY IN THE DEVELOPING WORLD

THE REAL ENERGY CRISIS

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OXFORD

ISBN 0 19 854425 1

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Oxford New York Toronto Melbourne
OXFORD UNIVERSITY PRESS
1980

way to go before it can significantly contribute to Brazil's energy supplies. But the Brazilian alcohol venture is just beginning, its potential is enormous, and it may yet become a model for an energy-hungry, and increasingly oil-poor world.

VI Africa

discovered and prospects of further hydrocarbon strikes, especially offshore, appear excellent. Above all, the country has the world's fourth largest hydro potential (about 660 billion kWh/year at average rate of flow, almost as much as the USA and about half of China's total) in the mighty flow of Zaire (Congo) River and its tributaries.

With the construction of first phases of giant Inga Dam near Kinshasa the harnessing of Zaire's power has barely started. Inga can eventually reach nearly 30000 MW of installed capacity and it has already been tied via a record-length high-voltage link with mineral-rich Shaba province 1700 km to the south-east. K. L. Adelman ('Energy in Zaire') outlines the details of this favourable situation and stresses Zaire's energy strength as the key factor in making it a future great continental power.

In contrast, Tanzania's energy situation is unenviable. The country produces only negligible amounts of coal and hydroelectricity and has to rely on imported oil to support a meagre modern energy consumption of below 100 kg of coal equivalent per capita. It is precisely in such circumstances where small-scale solar technologies might offer the best solution to the rural energy modernization.

The US National Academy of Sciences and the Government of Tanzania held a joint workshop in 1977 to determine the cost of five solar technologies—small hydrogeneration, windmill power, biogas, photovoltaic cells, and flat-plate solar collectors—and to compare it with costs of diesel-generated electricity and with the transmission from the national grid. N. L. Brown and J. W. Howe ('Solar energy for Tanzania') present detailed results of the workshop's estimates and see them as encouraging enough to initiate serious testing of the technologies in Tanzanian villages.

The future development of most African countries will continue to be one of the least successful chapters of the world's economic progress. The continent's energy reserves are relatively poor: less than 3 per cent of the global coal, and about 14 and 11 per cent of crude oil and natural gas, the latter two being overwhelmingly concentrated in Arab Africa. Barring major new hydrocarbon discoveries or a massive and speedy harvesting of solar energy, most of the black African states thus face an energy-poor future, a situation made worse by low export earnings, chronic indebtedness, and widespread political instability.

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their full output quota. The result was that production improved steadily, and then rose sharply in the latter months of the year in response to the shut-down of exports of Iranian crude and the resulting world shortage. Output averaged 1.91 million b/d in 1978 and rose to 2.40 million b/d in first-half 1979.

State participation

At present, nine companies or partnerships produce oil in Nigeria. The largest, accounting for over 50 per cent of the country's output from just under half of the licensed area, is Shell (which operated jointly with BP until BP's nationalization in August 1979). Producing from 79 onshore fields in the Niger delta region, Shell also manages a large network of crude oil pipelines and operates two big export terminals at Bonny and Forcados. Gulf, Mobil, and Agip-Phillips produce from 16, 12, and 13 fields respectively, Gulf accounting for about 15 per cent of total output and the others a little less. (Gulf with fields in the west of the delta, exports via the Escravos terminal, while Mobil's fields in the eastern part of the delta supply Qua Iboe terminal. Agip-Phillips export at Brass River terminal.) Of the smaller producers, Elf and Texaco account for just over 5 per cent of total output between them, with Ashland, Pan Ocean, and the Tenneco–Mobil–Sunray group contributing the remainder.

All of these companies operate in partnership with the Nigerian National Petroleum Corporation. This is the state-owned oil company, formed in 1977 through the merger of its predecessor (known as the Nigerian National Oil Corporation) with the Ministry of Petroleum Resources. NNPC thus meets two important needs: as a state-owned company, active in its own right as well as in partnerships with the international oil companies, it is playing a part and reaping the rewards from Nigeria's oil; while as an arm of the government, its acts in a regulatory capacity to ensure that the oil is being exploited in the nation's best interests.

The NNPC also holds the state's 60 per cent shares in producing companies. State participation in Nigeria's oil industry began in 1971, the year the country joined OPEC and the first year of operations of the NNOC. An agreement with Elf's subsidiary Safrap gave it a 35 per cent interest in concessions including the Obagi producing field in return for permission to bring the field back on stream—it had been shut down during the civil war. This first hurdle crossed, NNOC went on to take a 33 per cent share in Agip-Phillips' licence areas, while new offshore licences claimed for the state a 51 per cent share. The breakthrough came in the middle of 1975, when the largest producer, Shell–BP, agreed to a 35 per cent state share in its operations, backdated to April of that year.

Such participation shares were considered high—and undoubtedly were, in view of the 25 per cent agreements usual in Middle East countries at the time—but General Gowon's government went on to seek a 40 to 45 per cent stake in the remaining three producers. Gulf, Mobil, and Texaco–Chevron (as it then was) entered into protracted negotiations over the package of terms, but were overtaken by events: in early 1974 the government demanded, and was granted, a 55 per cent share in each of Nigeria's producing companies. This was raised to 60 per cent in July 1979.

With title to over half of Nigeria's oil output the state company can in theory sell about 1.4 million b/d at peak production. It experienced at first some difficulty in building up its direct international sales, however. Companies were asked to take some 'buy-back' crude, and on occasions part of NNPC's 60 per cent entitlement was left in the ground. (This latter practice does not affect the companies' liftings, which are calculated at 45 per cent of the 'allowables' production rates for each field, fixed by the NNPC in consultation with the companies with the objective of achieving the best production consistent with maximum overall recovery from the reservoir.)

Although NNPC has held a share in the operations of the producing companies since April 1974—and over the subsequent 4 years gained a full equity share through the completion of the government's compensation arrangements—it has been content to confine its intervention to general policy matters, leaving the day-to-day running of the producing companies to its US and European partners. But this is a matter of expediency rather than policy; the state company has found it consistently difficult to attract qualified personnel in the numbers required, despite terms of employment which are said to compare well with those offered by private companies. It has also been hampered by the somewhat limited degree of independent action allowed it by the government.

New relationship

However, after several years of steadily gaining expertise and the nucleus of its staff, the state company appears now to be in a position to play a more positive role in the development of Nigeria's oil. This is evidenced by the issue of exploration permits for new areas on terms other than the previous 60 per cent participation basis. The NNPC proposes to issue exploration and production licences for blocks within its reserved territory—which amounts to the whole of the country and the offshore with the exception of existing concessions in the Niger delta, plus relinquished concessions—on terms related to the likely prospects in each block. In each case, NNPC will take a more active involvement in development of these areas, a policy which amounts to a new relationship between the state company and the international oil companies.

Under the new terms, development contracts (which retain for the NNPC ownership of the oil) will be offered for areas where oil has been found but not as yet exploited, while production-sharing contracts and work-obligation contracts which could lead to a production share will be offered for areas where the prospects are more uncertain. NNPC will therefore make a contribution in terms of manpower and finance towards the development of these areas, and will be entitled in return to a greater share of the proceeds than it receives under 60 per cent participation terms.

Greatest interest will be shown in blocks likely to be offered in the Niger delta area's near-offshore—an offshore area of great potential which is already being exploited by the major companies under existing terms. It was here that the NNPC carried out its first drilling programme on its own account, which concluded in the spring of 1977 with four of the six wells drilled testing oil from multilayered reservoirs. (Reservoir thickness with the fifth well was considered insufficient, while the sixth was dry.) Twelve wells are scheduled under the second drilling programme, the first of which has been completed as a discovery.

Drilling work is also expected to begin, under the new terms, in Nigeria's other main petroleum prospects (besides the Niger delta)—the Anambra basin (just to the north of the delta), in the Chad basin (in the north of the country to the south of Lake Chad) and in the Sokoto basin in the north-west. A considerable amount of seismic work has been carried out in these areas but, owing to their distance from the coast, companies have not been enthusiastic about their potential. Finds would need to be very sizeable to justify the cost of a pipeline, and in any case geologists feel that the Niger delta still has good potential for producing worthwhile oil finds.

The Niger delta, in fact, has been one of the most productive areas in the world in terms of the relationship between wildcat wells drilled and oil finds. But it is a feature of the delta that oil is found in relatively small deposits, instead of in large Middle-East-type reservoirs, which can only flow at economic rates for a short time. A plants—although units are now under construction) means that high-value streams such as aromatics from the refineries are, of necessity, being used in petrol. This is wasteful, and results in the anomaly of 97 octane fuel being supplied for the local market —which, in view of the preponderance of Japanese cars in the country, could be met with fuel of a much lower grade. Warri's production is to be distributed throughout the country via a 3000 km network of pipelines and 19 storage depots, promising 'an end to gasoline shortages', according to the NNPC.

Using the gas

In common with many other OPEC countries Nigeria has only recently realized the potential of its second-largest energy resource—natural gas: For many years the gas, known as associated gas and produced together with the oil, was regarded as a by-product of little value; small quantities were used for electricity generation and other purposes at oilfields, but the rest was flared off. This is still the situation in Nigeria, with only a few per cent of the 18000 million cubic metres produced annually being utilized. But the technology for liquefying the gas and transporting it in refrigerated tank ships to consumers in Europe and the USA has developed rapidly; it is costly energy compared with crude oil, but in the view of many forecasters natural gas is the fuel which is best placed to meet the predicted 'energy gap' of the mid and late 1980s.

Nigeria's plans for exploiting its gas now centre on the construction of one large liquefaction plant at Bonny, to have an eventual capacity of 1600 million cubic feet/day (equivalent to some 16500 million cubic metres/year). This is to be built by a consortium of oil companies, with the state's NNPC taking a 60 per cent share; the cost is estimated at between $4500 million and $4900 million, with completion planned (very optimistically) for the early 1980s.

The plant will be fed with gas from the number of gas-only fields found in the delta in the course of oil exploration, in addition to associated gas. There should be no lack of supplies—one geologist commented recently that the delta is considered more of a gas province than an oil province. Nevertheless, a large pipeline network to gather the gas at Bonny will be necessary, and in view of the difficult terrain the cost of this is likely to be very great. Recognizing the difficulties, the government has said that it expects to be involved in this stage of the project to the extent of at least 85 per cent. The government will also take a 50 per cent holding in shipping facilities.

But Nigeria's reserves of gas are believed to be very substantial, and it would clearly be undesirable to continue wastefully flaring a premium, clean, and sought-after energy resource. Gas reserves have been estimated variously at 1250000 million cubic metres (a Shell figure), 1422000 million cubic metres (an end of 1974 US Federal Power Commission figure), and between 1650000 and 2100000 million cubic metres (according to Nigerian scientists), indicating a life of 75 years at the liquefaction plant's full capacity. Reserves could therefore be as great, on an energy-equivalent basis, as two-thirds of the country oil reserves.

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Hydro power plans in Nigeria

G. V. ECKENFELDER

The Niger, 4300 km from source to mouth and draining 1.9 million km^2 ranks third among the rivers of Africa, after the Zaire and Nile, in the extent of its region of influence. The main stem of the river traverses four countries—Guinea, Mali, Niger, and Nigeria, flows along the boundary between Benin and Niger, and its tributaries reach into Ivory Coast, Upper Volta, Benin, Chad, and Cameroun. Much of its course is in the Guinea, Sahel and savannah regions of West Africa where it forms the only significant source of water. Its influence and that of its tributaries are thus felt in nine countries. It has been called the River of Sorrow and of Hope—sorrow because in times of drought those who depend upon it sometimes starve, but when the rains come and the floods flow over the bottom lands, there is plenty and people rejoice.

The Niger rises in the highlands of Guinea, less than 300 km from the Atlantic Ocean. It thence flows north-east 600 km to the great inland delta of Mali where it is dispersed in a maze of channels, lakes, and swamps, and where a substantial amount of its flow disappears in evaporation and into the aquifer. This region is, economically, one of the most valuable of the Upper Basin because, in normal years, it supports an important agricultural society, and its channels and backwaters teem with fish.

Below the delta region the channel is once more well defined, and the river continues its course across arid plains and through the cities of Timbuktu, Gao, and Niamey, entering Nigeria below Goya, at a point where the three countries, Niger, Benin, and Nigeria come together. The Niger then courses through open and lightly wooded and semi-arid savannah country to Lokoja, where it is joined by the Benue, its major tributary. Below Lokoja the climate changes to humid equatorial, with increasingly heavy forest. The river enters its coastal delta below Onitsha, where swamp and rain forest prevail and where it divides into a myriad of channels. Here, the great wealth of Nigerian oil is found.

Hydrologically, the river in Nigeria is characterized by two distinct floods. The Black Flood, named because the resulting water is relatively free of sediment, thus appearing dark, is derived from the summer rains of the Guinea highlands. Because of the delaying effect of the delta region of Mali, combined with the flat gradient and slow velocity, the Black Flood does not appear in central Nigeria until the following December.

The second flood, the White Flood, so called because the silt it carries gives the water a light colour, comes from the rain which falls on the basin in northern and central Nigeria during August and September.

First published in *Energy International*, Vol. 14, No. 7 (July 1977), pp. 20–2. Reprinted by permission of the author and *Energy International*.

Engineering Company to undertake detailed investigations and a feasibility study of the site, which has now been completed. The firm are now proceeding with detailed engineering and design. Construction is scheduled to start in 1978, with completion in 1982.

In addition to the regulated flow from Kainji, Jebba will utilize the discharge from 41 000 km^2 of intervening drainage area. Records dating from 1954 indicate a minimum incremental flow of near zero during the driest period and a maximum monthly flow of 1820 m^3/s. The average, for the period 1954 to 1975, is calculated to be 132 m^3/s. On the basis of these flows added to the discharges from Kainji, an installation of 500 to 600 MW is warranted.

Whereas at Kainji, massive igneous and metamorphic rock exists at shallow depth along the entire length of the dam, the situation at Jebba is less attractive. At some distance below Kainji the Niger enters a deep submerged gorge, evidently carved at a time of low sea-levels or possibly during a period of continental uplift. At Jebba this sand-filled slot meanders from side to side of the river, and has a depth of about 75 m and a width of some 150 m. The banks, as well as a number of islands in the reach under consideration, are mainly composed of hard, jointed gneissic quartz-rich rock. These geological characteristics govern the type and arrangement of structures. The spillway, intake, powerhouse, and navigation locks must be situated on the shore where the rock is exposed or at shallow depth. The river section, with its great depth of unconsolidated sediments, requires a fill-type dam with a suitable measure of seepage control. This could consist of a concrete diaphragm wall placed in a slurry-filled excavation, a slurry trench, or an upstream blanket. The studies thus far lean towards a blanket. A number of alternative layouts, on three possible axes have been examined, in the field and in the course of the office studies, and the optimum arrangement is emerging from an examination of safety, cost, schedule, and convenience.

Jebba is well situated with respect to NEPA's transmission system, there being already in existence near Jebba a 330 kV substation fed by Kainji. Access to the site is favourable, with both railway and paved highway from Lagos crossing the river within 3 km. There is also the possibility of transport to the site by shallow-draught river craft from the mouth of the river.

The Niger, below Jebba and in its tributaries, offers a substantial potential for additional development. The sites at Lokoja, under investigation, and Onitsha have an estimated capacity of 1950 and 750 MW respectively: dams here will further improve conditions for navigation. On the Kaduna, the Shiroro site now under development will produce 600 MW, and Makurdi on the Benue, now under investigation, 660 MW. The Cross River, which rises in Cameroun and flows into the sea at the eastern extremity of the Niger Delta, has a number of sites, the most interesting of which is Ikom, where a preliminary feasibility study is being carried out. It has an estimated potential of 400 MW. The foregoing six sites, including Jebba, are considered to be the most promising, and have a total estimated capacity of 4650 MW at 50 per cent capacity factor. Other sites in the Niger and Cross Basins have been subject to reconnaissance or preliminary surveys. The 10 best of these have an estimated total capacity of about 2700 MW at 50 per cent capacity factor.

It is not possible, within the scope of this article, to discuss the sequence and timing of the expansion of NEPA's generating facilities. It suffices to say that the six projects—Jebba, Shiroro, Lokoja, Onitsha, Makurdi, and Ikom—are being seriously considered for development over the next decade or so and Jebba and Shiroro are being investigated in depth.

We have seen that Nigeria is relatively well endowed with hydro sites. This, combined with substantial reserves of oil and gas, places Nigeria in a fortunate situation with regard to electrical power.

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Energy resources and demands in Zambia and in Africa south of the Equator

ENAR ESKILSSON

Energy situation in Zambia

Zambia is fortunate in being blessed with enormous amounts of sunshine and with plenty of water in its many rivers which offer suitable sites for hydro-power development. Apart from this, Zambia has appreciable coal reserves, but no other fossil fuels and so far no useful geothermal resources, and, though further investigations may be worthwhile, petroleum products have to be imported.

The main river systems of Zambia are the Zambesi and the Luapula. The former rises where the borders of Angola, Zaire, and Zambia meet. In its lower reaches it forms the boundary between Zambia and Rhodesia. It has two main tributaries—the Kafue and the Luangwa, both confined to Zambia, except that the latter forms the boundary between Zambia and Mozambique for a short distance before its confluence with Zambesi which finally through Mozambique, discharges itself into the Indian Ocean. Luapula flows northwards along the border between Zaire and Zambia into Lake Mweru and then to Zaire river.

The three major existing hydro developments in Zambia are Victoria Falls on Zambesi river 108 MW, Kafue Gorge on Kafue river 900 MW, and Kariba North on Zambesi river 600 MW, giving altogether 10 500 GWh firm energy.

Further hydro development on Kafue river would produce 3000 GWh. On the border with Rhodesia new sites for hydro development on Zambesi river as joint ventures with Rhodesia will ultimately yield around 20000 GWh, of which 10000 GWh for Zambia. An extension of Kariba North may add 600 GWh to the available energy.

A development on Luapula river with a number of stations could produce 5000 GWh which has to be shared with Zaire, thus for Zambia 2500 GWh. Minor schemes in different rivers will add altogether around 400 GWh to the available energy.

The future hydro-power development in Zambia which now can be foreseen corresponds to a total amount firm energy of 16 500 GWh. Together with the existing supply of 10 500 GWh Zambia's total hydro-power resources thus amount to 27000 GWh which is almost five times the present total electricity consumption in the country.

The main transmission system in Zambia is arranged for 330 kV. This interconnected system covers both Zambia and Rhodesia and is over a 220 kV transmission line connected with the transmission system in the Shaba Province of southern Zaire with the industrial area around Lubumbashi. An international exchange of electric power with Zaire has been in existence since 1956

First published in the *Transactions of the Tenth World Energy Conference*, Istanbul, Turkey, September 1977. Paper 1.4–5. Reprinted by permission of World Energy Conference.

million kWh and the corresponding installed capacity in all power stations was 13400 MW.

South Africa has thorium resources and extremely rich uranium resources of lower cost and is in this respect the second country in the world. There are 298 million kg of uranium with a maximum cost of $36 per kg. A nuclear power station is being planned near Cape Town to be commissioned late 1982.

Petroleum products are imported, most of the crude oil being refined in Durban. Of the total needs of refined oil of around 11000 million kg in 1974, more than 10 per cent is produced from coal within the country.

Swaziland has appreciable hydraulic resources which are partly developed and quite large coal resources, and in this respect ranks second among the 16 countries in southern Africa. A 132 kV interconnection exists with South Africa. Plans have been discussed to erect a large thermal station, thus creating a more viable project and to export the main part of the energy.

In Tanzania there are appreciable resources of coal but above all there are great hydro resources. Tanzania in this respect being the second country after Zaire in southern Africa. The biggest hydro plant is Kidatu in Great Ruaha river with a capacity of 200 MW. From the site goes a 220-kV transmission line to Dar-es-Salaam.

Uganda possesses no fossil fuels but has an abundance of hydro power resources, most of them unharnessed. The river Nile has a drop of over 500 m between Lake Victoria and Lake Albert corresponding to a generating capacity of 3000 MW. However, the major energy source has been Owen Falls for 150 MW at the outlet of Lake Victoria. A part of the capacity has been delivered to Kenya over a 132-kV transmission line.

Zaire's hydroelectrical potential is from one source estimated at 100000 MW but other sources have indicated 180000 MW. This sum corresponds to one-third of Africa's hydroelectric resources and amounts to around 700000 GWh. The biggest project for power generation is the Inga complex in Zaire river with one of the highest hydroelectric potentials in the world but with an ultimate capacity of some 40000 MW. The first stage has a capacity of 351 MW and the second near completion 1272 MW. This second stage is combined with a high voltage direct-current transmission link to Shaba Province near the border to Zambia. The voltage is ±500 kV, the distance 1700 km, and the ultimate capacity 1120 MW. The huge hydro-power resources in Zaire could, as far as energy is concerned, be sufficient to meet the total electricity requirements in all the 16 countries in southern Africa up to the year 2000.

Zaire has not only great hydro-power resources but also appreciable amounts of coal, oil, natural gas, oil shale resources, and uranium.

With regard to petroleum products the total requirements in 1974 amounted to 800 million kg. These products were mainly imported as crude oil and refined in a refinery for 750 million kg per year located at Matadi near the western coast of Zaire. Different products have been imported from neighbouring countries but also exported, especially fuel oil.

Summary of electricity requirements

The result of the study regarding electricity requirements in the different countries is shown in Table 23.1. A forecast has been made for every country giving the estimates for 1984. It should be added that it has been difficult to obtain information from a few countries. It has therefore in a few cases been necessary to make rough estimates or guesses.

To make the picture of the countries more significant, figures are given both for the size of the country and the number of inhabitants. The most densely populated rural areas in Africa are Burundi and Rwanda with 132 and 162 inhabitants respectively per square kilometre. This can be compared with Botswana and Namibia with less than 1 inhabitant per square kilometre or with Angola and Zambia with 5 or 6 inhabitants respectively per square kilometre.

Table 23.1. Estimated population and electricity requirement

Country	*Area thousand km²*	*Population million end 1974*	*Electricity requirement (GWh) 1974*	*1984*
Angola	1246	6	1000	3000
Botswana	712	0.6	300	500
Burundi	28	3.8	300	700
Kenya	644	12.8	1100	2400
Lesotho	30	1.2	30	100
Malawi	118	5	210	550
Mozambique	783	10	700	2000
Namibia	835	0.8	400	1200
Rhodesia	389	6.1	5700	14000
Rwanda	26	4.2	300	700
South Africa	1223	24	67000	130000
Swaziland	17	0.5	150	350
Tanzania	936	14.5	570	1500
Uganda	236	11	700	1000
Zaire	2344	24.5	4000	15000
Zambia	752	4.7	5700	11000
Total	10319	129.8	88160	184000

The total electricity requirement increases from 88160 GWh in 1974 to 184000 GWh in 1984 or from 679 to 1418 kWh per capita counted as an average value and related to the population in 1974. If the yearly population increase is 2 per cent the consumption per capita in 1984 will be 1163 kWh. Assuming an average load factor of 70 per cent and a necessary stand-by with margin for the different systems of 20 per cent the result is a total required capacity of 18000 MW in 1974 and 37500 MW in 1984.

World energy conference survey of energy resources 1974

The survey has information about most of the 16 countries but the material is in some cases rather old and dated between 1960 and 1973. It gives the amounts for installed and installable capacity based on average annual flow conditions and is expressed in GWh (millions kWh) shown in Table 23.2.

The result is around 1 million GWh which is about half of the estimated hydroelectric resources in Africa which are estimated at around 2 million GWh.

The survey gives the amounts for recoverable solid fuel reserves in thousand million kg, as shown in Table 23.3. The

Table 23.2

Angola	48320
Botswana	8952
Kenya	53760
Lesotho	2600
Malawi*	400
Mozambique	45160
Namibia	3600
Rhodesia	20000
South Africa	8546
Swaziland	10080
Tanzania	83200
Uganda	72000
Zaire	660000
Zambia†	15336
Total in GWh	1031954

*The actual resources are 5300 GWh.
†The actual resources are 27000 GWh.

distance of 200 km has proved to be of great importance for both Zaire and Zambia. Large amounts of energy have been transported over the border from time to time in different directions aiming at improving the power balance and strengthening the reliability.

The connection might be of still greater importance after the completion of the HVDC link between Inga Falls and Lubumbashi, but only after a strengthening of the link, for instance with a 330 kV line, giving possibilities for a firm transfer of up to 600 MW.

With Cabora Bassa, only 350 km from the nearest point of the existing 330 kV transmission system in Zambia and Rhodesia, there seem to be ample opportunities and great advantages with a connecting 330 kV line. Such a line could be useful both for general exchange of electric power and for facilitating further development on both sides. The cost for a single line would be around 30 million dollars. The corresponding unit cost for a transfer of 600 MW at a load factor of 70 per cent is around 0.08 cent per kWh.

Owing to the fact that Zambia would be located in the centre of the envisaged interconnected system it seems natural that the national control centre under erection in Lusaka could play an important role in the administrative and operative achievements necessary for an efficient utilization of available resources.

Co-operation regarding electricity distribution started a long time ago between Kenya and Uganda and has been seriously discussed between Kenya and Tanzania. These three countries (the East African Community) are rather densely populated and have similar requirements of electricity. They have advantages of short distances in erecting interconnections. Suitable voltages 132 and 220 kV are already established and a further development for mutual benefit seems natural.

With regard to electricity connections it is in the first place a question about extensions of existing lines and at a later stage a possible introduction of a higher voltage. Owing to the fact that several big hydro developments are under construction or being planned the justified interconnections have to be carefully studied.

A co-operative movement has been introduced regarding petroleum products and this arrangement has certainly contributed to the development in the energy field. It concerns import with shipping and agreements with oil-producing countries and oil companies. It also concerns refineries, storage facilities, and distribution.

In South Africa there is a large transmission system with, in 1974, around 5000 km of 400-kV lines and 14 000 km of lines for 275, 220, and 132 kV. Connections are established with Lesotho, Swaziland, and southern Mozambique. This system is being used for distribution of 75 per cent of all electricity generated in the 16 countries in southern Africa. In 10 years this percentage might be reduced to 70 but here is still a dominating centre from many points of view.

The long-range planning to meet the overall energy requirements in southern Africa must be to utilize the enormous inexhaustible hydro-power resources in the northern countries, especially in Zaire, to meet the growing demand of energy in the southern countries. Two important initiatives have been taken in this respect with HVDC lines, one in the West from Inga Falls to Lubumbashi 1700 km, and one in the East from Cabora Bassa to Apollo 1400 km.

It seems realistic to consider such connections in a future with higher capacities and over longer distances. The distance from Inga Falls to Johannesburg is about 3000 km. A double bipolar line for 6000 MW would probably, with present prices, cost around $1600 million. The corresponding unit costs for a transfer of 6000 MW at a load factor of 70 per cent will be around 0.45 of a cent per kWh.

If and when available hydro-power resources for reasonable costs in the East African Community cannot keep pace with

the requirements one could envisage another big transmission connection from the Inga Falls to reinforce the supply in Uganda, Kenya, and Tanzania. Such a connection ought to have a distance of around 3000 km to the centre of the region.

The conclusion is that utilization of direct current has provided ample opportunities for transfer of high amounts of electric energy over vast distances at reasonable cost.

Petroleum products and pipelines

Crude oil has been found in Angola and Zaire, in both countries in rather large quantities. Natural gas has been found in Angola, Mozambique, Rwanda, South Africa, and Zaire. The total amount is about the same as for crude oil. The total amounts of recoverable reserves of crude oil and natural gas are small as compared with coal, and also in comparison with oil from oil shale and bituminous sand which have been found in Angola, South Africa, and Zaire with especially large quantities in Zaire.

The total consumption of petroleum products may be estimated at around 18 000 million kg (in the whole of Africa around 50 000 million kg). Known refineries are established at Luanda in Angola, Mombassa in Kenya, Salisbury in Rhodesia, Durban, and other places in South Africa, Matadi in Zaire, and Ndola in Zambia. The total refinery capacity might be somewhat larger than the consumption (in the whole of Africa 62 000 million kg). The recoverable reserves of crude oil for all 16 countries in southern Africa are only around eight times the present annual consumption.

Known pipelines are the following:

Dar-es-Salaam in Kenya to Ndola in Zambia 200 + 300 mm 1700 km;
Beira in Mozambique to Salisbury in Rhodesia 500 km;
Durban to Rand in South Africa, 300 mm, 700 km.

A comparison between costs for transporting energy in the form of electricity and the corresponding costs for transport of oil in pipelines does ordinarily result in lower costs for electricity over transmission lines. For very large quantities, however, the result can be the opposite. An example is given below.

The costs vary within a wide range, depending upon the site conditions. 6000 MW electricity can be transported 1000 km over a double bipolar high voltage direct current line costing 555 million dollars. The transported energy in a year at 100 per cent load factor is 52 560 million kWh or 189×10^{15} J. The unit cost is thus 0.106 of a cent per kWh or 0.029 of a cent per MJ.

A corresponding transport of 4360 million kg oil per year containing the same amount of energy can be done with a pipeline with a diameter of 360 mm costing around $150 per m or in total $150 million. This gives a unit cost of 0.008 of a cent per MJ.

If the oil is going to be used for generating electricity the transported amount has to be 12 600 million kg. The corresponding cost for a 610-mm pipeline is $255 per m or totally $255 million. The unit cost in this case will be around 0.05 of a cent per kWh or 50 per cent of the transmission line costs.

It can be finally concluded that there seems to be no justification for such large transfers of energy in the form of oil in southern Africa but certainly with regard to electricity. To transport gas is more expensive than to transport oil. A pipeline with a certain diameter can transport four to five times as many calories of oil than calories of gas.

Conclusions and recommendations

Southern Africa is a region with enormous natural possibilities and potentials of value for mankind. It has firstly in many countries, a good climate and suitable soil for agriculture, and in addition vast areas of undeveloped land which could be cultivated. Increased initiatives could create huge crops of different kinds and a variety of fruits, plants, etc., throughout the country. He assured the oil companies that just compensation would be forthcoming, which somewhat eased the jolt.

There are a host of possible reasons for Zaire's nationalization of the petroleum industry. First and perhaps foremost, the industry was the largest foreign concern after the President's dramatic 30 November 1973 speech which effectively Zairianized the economy by ordering the takeover of all medium and small businesses and agricultural activities. The decision to create PetroZaire, announced just 3 weeks later, was merely a further step in the nationalization process already under way. Secondly, Zaire was obviously disturbed by the oil companies' continual requests for prices increases and by their difficulty in supplying jet fuel, a precious commodity for President Mobutu who considers the Air Zaire fleet, especially the Jumbo jets, his biggest prestige item.

In addition, Zairian officials may well have believed that the oil companies were making a fortune in the country, a profit they would like to have, and that they would get a better deal from doing business directly with the Arabs. This seems to have been a key factor. President Mobutu had been courting the Arabs before this time, breaking diplomatic relations with Israel shortly before the outset of the latest war despite years of friendly relations between the two countries and extensive military training programmes in Israel for Zairian officers. The President further cultivated 'our brothers, the Arabs' with a highly publicized trip to Algeria, Libya, and Egypt just before nationalization (November 1973) and to Saudi Arabia, Kuwait, and Iran just afterwards (December 1973 and January 1974). Despite the diplomatic offensive, the Zairian efforts have in the main proved futile since the Arabs have refused to give Zaire any special arrangements, whether in terms of long-term supply contracts or reduced prices. In fact, Zaire now pays $2 or $3 per barrel more to the Arabs than to the large oil companies for petroleum products.

Finally, there are the inevitable rumours that the government nationalized the oil industry for some more mysterious reason. One hears that the government was furious at Fina, a Belgian company, for allegedly diverting tankers from Zaire to Belgium during the crisis in Europe. Also, rumour has it that the Arabs were contemplating large investments in the copper industry of Zaire, foreign capital that the President would eagerly welcome. These and other stories persist even though there are no hard facts to substantiate them.

Regardless of the government's motives, the oil companies soon found themselves nationalized. Some minor exceptions were allowed, such as the oil refinery in which Zaire already owns 50 per cent with an Italian firm, Ente Nazionale Idrocarburi (ENI) owning the rest. Part of the distribution network in the East was left in private hands for another year. Still, for all intents and purposes, PetroZaire became the oil industry in Zaire, even though for months it existed only as a name, and not as an organization, while the oil companies continued to supply and transport petroleum throughout Zaire.

For over 6 months following the nationalization announcement, PetroZaire actually consisted of only two persons, the Director and his deputy, who were busy preparing plans to consolidate the four major companies into one Zairian structure. In December 1973, there were approximately 150 expatriates working for the companies, most of whom continued to work as before until April or May 1974. At that time, Fina released much of its staff—now about 33, down from 85—and Shell removed all of its expatriate employees. Out of the original 150 executives and managers, there are now some 40 or 45 expatriates working either for the oil companies under PetroZaire or for PetroZaire directly.

Hence the transition from a private to public petroleum industry in Zaire was a smooth one with the major companies co-operating. Of course they helped PetroZaire get established in part to assure receipt of compensation for all the equipment and facilities taken over in the country. While the government has fully agreed to just compensation—which the companies estimate at upwards of $160 million—little has actually been done. Zaire has not even begun negotiating amounts as the officials consider the matter still under 'careful study'. Even after 1 year, the oil companies remain optimistic about getting their money, though perhaps not as much as requested. They believe that Zaire must pay, or ruin its international financial rating. It simply cannot keep encouraging large foreign investment after refusing to compensate a large industry which was nationalized.

The oil companies have helped PetroZaire not only to encourage full compensation but also to protect their future business arrangements in the country. All four of the major companies are involved in exploration activities in Zaire, efforts which have not been affected by nationalization. In addition, some continue to work on contract for Petro-Zaire. For example, Mobil Oil still operates the elaborate machinery for making lubricants, and supplies aviation fuel, some crude oil, and special products used for the paint and textile industries. Hence the companies have had their own reasons for helping PetroZaire through the transition period, which formally ended on 1 January 1975 when final consolidation of the industry in Zaire took place. The four accounting, sales, distribution, public relations, and administrative offices of the oil companies are now centralized and effectively integrated in PetroZaire.

The new, consolidated PetroZaire should not have any major supply problems during its first year of full operations. Present plans call for Zaire to receive half its crude oil from Libya and the other half from Iran or possibly Algeria and the major oil companies. In the past, Zaire imported 669193 tonnes of crude oil, valued at $12.7 million in 1970; 672033 tonnes valued at $14 million in 1971; 717018 tonnes valued at $16.2 million in 1972; and 179095 tonnes valued at $4.1 million for the first 3 months of 1973.

While the Arabs have agreed to supply this crude oil, and some refined products as well, they do so at fairly high prices since Zaire is a relatively small consumer. Also the Arabs have refused to sign any long-term contracts with Zaire to guarantee continual supply over the years. It seems that they regard Zaire more as a burden than a brother. Because of such treatment, over which Zaire has not publicly protested as yet, the government found itself in the embarrassing position of doubling domestic petroleum prices on 1 May 1974, just a few months after the oil companies requested slight price increases. At present, domestic prices are extremely high, though they are uniform throughout the country. Premium petrol sells for $1.55 per gallon, regular petrol for $1.44 per gallon, paraffin for 76 cents and diesel-type fuel for 93 cents per gallon.

Many of these products are produced in Zaire at the refining plant outside Moanda on the Atlantic Ocean. SOZIR, as it is called, plans to increase its production from an annual output of 750000 tonnes in 1972–3 to over 1.7 million tonnes of refined products per year. Actually the refinery was specifically designed to process the type of crude oil supplied by the large companies. Consequently, it works less efficiently refining the Libyan crude, which is of a slightly lower quality. There has been some thought given to changing the equipment or expanding the plant to better accommodate Libyan oil, but nothing has been done. No action is likely until Zaire's offshore oil is analysed and production begins.

Zaire gets most of its imported refined oil from Algeria. The supply to eastern Zaire comes by ship to Lobito, Angola, and along the Benguela Railroad into Zaire, and from Kenya and Tanzania. Zambia also supplies the Shaba (ex-Katanga) Region, sending mostly diesel fuel for the heavy mining equipment, motor oil, and jet fuel for the Lubumbashi airport.

PetroZaire's outlook for the immediate future appears fairly good. One main problem area is the supply of 15000 tonnes mishaps of working in a developing country. For example, the initial survey team dropped small aluminium poles by helicopter along possible construction routes, only to find that when they flew back, all the carefully placed markers were gone. Apparently, they were hot items in the local markets, selling for a few cents apiece.

Following the construction of Inga II and and Inga–Shaba line comes Inga III, presently in the planning stages. Its output could reach 1.8 million kW with the cost per installed kilowatt around $210. At the completion of Inga IV and Grand Inga—still in the discussion stage—there is the potential for more than 30 million kW with the final cost per kilowatt around $70. This would make Inga far and away the most powerful hydroelectrical plant in Africa, more than ten times the capacity of the Aswan Dam (2.1 million kW) and five times that of Cabora Bassa, Mozambique (6.32 million kW).

Naturally this tremendous energy potential has important political repercussions, both domestically and internationally, for Zaire. The Inga–Shaba power line binds the country together, perhaps irrevocably. The Shaba Region with all its copper production and the one region with a strong sense of solidarity and a history of secessionist sentiments, will be almost totally dependent on the Kinshasa area for its power. Apparently this factor was decisive in the construction of Inga and especially of the Inga–Shaba line. Government leaders well realized that the power for the copper industry could be supplied from Zambia and from local water sources, probably at considerably less cost than the Inga project.

Conclusion

Internationally, the country's exportation of both petroleum and hydroelectrical power will place Zaire as a key energy provider for central and much of southern Africa. There are already plans afoot to export energy to Zambia, Tanzania, Rwanda, Burundi, Mozambique, Rhodesia, and the small African republics to the north of Zaire. This places Zaire in a strong position, along with Nigeria, as a leading political and economic force of Africa, and may prove invaluable in helping President Mobutu realize his dream of great continental power and world prestige.

25

Solar energy for Tanzania

NORMAN E. BROWN AND JAMES W. HOWE

Most of the people in the developing countries of Asia, Africa, and Latin America live in rural areas. Progress in these areas depends on finding substitutes for human muscle energy, which is now relied on for many village tasks.

The prohibitive costs of large central generators and massive transmission and distribution systems, as well as the slow pace of the spread of rural electrification programmes, discourage hopes that rural energy needs can be met with a national electric grid. Hence, we have inquired into the potential of small-scale technologies that use renewable energy sources coming from the sun. Current solar energy comes from four major systems: (i) photosynthesis, which is the basis of all life, both plant and animal; (ii) the water cycle, which is driven by the sun; (iii) wind, caused by the atmospheric pressure differences due to changing amounts of solar energy falling on different places; and (iv) direct sunshine. Proven small-scale technologies exist for using each of these solar energy systems.

In photosynthesis, biogas plants use anaerobic bacteria to turn animal, human, and crop wastes into methane gas and, at the same time, leave a residual slurry that is useful for fertilizer. It has been reported that there were 1.2 million biogas plants installed in China in the first 6 months of 1976 alone, and that 4.7 million are now in operation.[1] The technology appears to be proving itself and is improving all the time. Methane can be used for cooking, crop drying, power generation, and various other purposes.

To make use of the water cycle, a number of very small hydroelectric generators are now being manufactured for as little as $800. Miniature units producing only a few hundred watts or a few kilowatts can operate either with a small dam or simply by the flow of a small stream. In China, it is reported, there are 60000 such units averaging about 40 kilowatts in capacity that successfully supply most of the electricity used by three-quarters of China's rural communes.[1] In the nineteenth and early twentieth centuries, most of New England's commercial power came from small hydro facilities.

Windmills had long since proved themselves in Holland and the plains of the United States before they were driven out of existence by rural electrification—originally based on coal and later on cheap oil.

At least two small-scale technologies are available to make use of the direct rays of the sun. One is a flat-plate collector for space- and water-heating, but which could also serve for activities such as crop and fish drying, distilling water, and refrigerating.

First published in *Science*, Vol. 199 (10 February 1978), pp. 651–7. Copyright 1978 by the American Association for the Advancement of Science. Reprinted by permission of the authors and *Science*. A revised version of this paper appears in P. H. Abelson and A. L. Hammond (eds.) *Energy II: Needs, Conservation and Supply* (AAAS, 1978).

Table 25.1. Solar energy applicability matrix. Animals are included as a solar technology (based on photosynthesis). For many villages the use of animals would represent a modernizing step. It includes the use of dung for burning or fertilizing.

	Energy use													
								Heating						
Solar technology	*Water pumping*	*Lighting*	*Cooling*	*Communications*	*Water desalting*	*Spinning*	*Sawing*	*Cooking*	*Space*	*Domestic water*	*Grinding*	*Drying*	*Transport*	*Fertilizer*
Solar cells (flat plate)	+	+	+	++	−	+	−	−	−	−	+	−	−	−
Flat-plate collectors	+	−	+	−	++	−	−	+	++	++	−	++	−	−
Concentrating collectors	+	+	+	−	+	+	+	+	−	−	−	−	−	−
Solar, stirling	+	+	+	+	−	+	+	−	−	−	+	−	−	−
Solar, rankine	+	+	+	−	−	+	+	−	−	−	+	−	−	−
Wind (mechanical)	++	−	−	−	−	+	+	−	−	−	++	−	−	−
Wind generator	++	++	++	++	−	+	+	−	−	−	++	−	−	−
Water (mechanical)	++	−	−	−	−	++	++	−	−	−	++	−	−	−
Hydroelectric	++	++	++	++	−	++	++	−	−	−	++	−	−	−
Bioconversion	−	+	−	−	−	−	−	++	++	++	−	++	−	+
Biogas	+	++	+	−	−	−	−	++	−	+	−	+	+	++
Draught animals	++	−	−	−	−	−	−	+	−	+	++	−	++	++

Symbols: ++, applicable; +, potentially applicable; −, not applicable.
Source: Adapted from a presentation by J. R. Williams at the Tanzanian workshop.

The other technology for collecting the direct rays of the sun to generate electricity is a solar cell or photovoltaic array such as that used to power spacecraft.

Such promising technologies could be useful for a variety of tasks in rural areas. This potential is described in Table 25.1, where 14 technologies are applied to 15 common village tasks with the result that there are 34 applications that seem useful and 39 applications that seem marginally useful.

But what of costs? Are these not all technologies that require years more of research or the establishment of mass markets to become cost competitive with conventional energy sources? So few good data have been kept on the costs and performance of such technologies in actual village situations that we cannot answer this question completely. However, some preliminary calculations suggest that at least five technologies now 'on the shelf' are, or soon will be, cost effective when compared with either diesel electric generation or the existing electric grid in the case of Tanzanian villages. These calculations were made in Tanzania during a 10-day workshop jointly sponsored by the US National Academy of Sciences and the Tanzanian National Scientific Research Council. For a week, this workshop group[2] poured over calculations of the costs of performing certain village tasks (i) with diesel motors, (ii) with electricity from the Tanzanian electric grid, and (iii) with five small-scale renewable technologies. The results surprised even the experts. Each of these five technologies appeared to be now, or soon would be, competitive with diesel. A number of them compete well with the electric grid for certain village tasks. These results are valid despite the assumption that capital to build the facility costs 10 per cent and must be repaid during the life of the equipment. In actual fact, a great deal of capital is often available to developing countries on far more generous terms. This is more advantageous to solar energy over the life of the project than to diesel power, because capital costs of the former are high relative to operating costs while the reverse tends to be more true of diesel power. Thus, for example, it may be possible to borrow nearly 100 per cent of the total life of project costs for a photovoltaic installation (since such costs consist nearly entirely of initial capital), whereas for the initial capital for diesel one could borrow only about one-eighth of the life of project costs. Hence cheap capital favours solar over diesel energy.

Of course the panellists recognized that a final determination of whether a given technology should be applied to a given village situation depends not only on the financial costs, but also on availability of resources, social obstacles, social benefits, institutional barriers, long-range power requirements, and long-range development goals. In the short time available to them, they focused on estimating financial costs of the technologies considered most likely to be applicable with the understanding that this was but a first step in the decision-making process.[3]

Basis for cost comparison

A hypothetical village of 300 families was chosen as a basis for estimating the magnitude of financial investment needed. It was assumed, for these initial installations, that the needs of each family could be met, on the average, by the use of 1 kilowatt-hour per day (300 kWh total) to be applied to lighting, operation of a village television receiver, radio communications, pumping water, or grinding grain. At this rate of energy consumption, Tanzanians receiving central-station generated electricity from TANESCO (Tanzania Electric Supply Company) would pay, on the average, about 0.93 shilling (*s*) per kilowatt-hour[4] (the US equivalent is \$0.113/kWh). It was assumed further that the 300 kWh/day could be supplied either on a 5-hour basis, that is, at the rate of 60 kW, or for 20 hours, that is, at a rate of 15 kW.

Table 25.4. Water requirements for supplying hydroelectricity by small-scale systems

Power (kW)	*Head (m)*	*Flow (m^3/min)*
	48	12
60	24	25
	12	50
	6	100
	24	6
15	12	12
	6	24

Table 25.5. Base data for cost of supplying hydroelectricity by means of small-scale systems

Item	*Lifetime (years)*	*Unit cost (s)*
Generator/turbine	30	4000/kW
Power conditioning	30	6/W
Batteries (85 per cent efficiency)	6	800/kWh

For such a loan, no payment is required for the first 10 years; the loan is repayable, in equal annual instalments over the next 40 years, at an annual interest rate of 0.75 per cent. For this example, this would mean a financing cost of 9.6 million shillings per year from years 11 through 50. If the energy generated were sold to the villagers at the cost figures calculated in Table 25.6, the annual income would be 53 million shillings if the loan were a conventional 10-year loan, and 35 million shillings if it were a conventional 30-year loan. This would provide the government with between 25 and 40 million shillings for other projects. On the other hand, if energy were sold at a rate just sufficient to meet the 40-year cost of the IDA loan, the rate would be 0.17s/kWh, a figure less than one-fifth the current price of electricity in Dar-es-Salaam, and a cost well supportable by the villages electrified in this scheme. (This is approximately 1s per week.)

The four hydroelectric cases considered were based on a use by the villagers of 200 watts of electricity for 5 hours per day. For cases 3 and 4, this is the total capacity of the system. For cases 1 and 2, however, the system would be capable of supplying energy at the same rate (60 kW) day and night for 24 hours. If this capacity were used

Table 25.6. Cost of small-scale hydroelectric systems (in shillings). The cost of dams and penstocks was not included

Item	*Case 1*	*Case 2*	*Case 3*	*Case 4*
Cost of equipment				
Generator/turbine	240000	240000	60000	60000
Power conditioning	360000	0	90000	0
Installation	60000	24000	15000	6000
Subtotal*	660000	265000	165000	66000
Battery storage	0	0	280000	280000
Installation	0	0	28000	28000
Subtotal	0	0	308000	308000
Total (approximate)	660000	270000	470000	370000
*Financing costs at 10 per cent annual interest rate**				
Annual cost in shillings†				
30-year loan	70000	29000	89000	78000
10-year loan	107000	44000	99000	82000
Cost of electricity (s/kWh)‡				
30-year loan	0.64	0.26	0.81	0.71
10-year loan	0.97	0.40	0.90	0.75

*Based on amortization of the loan in equal yearly instalments.
†In both cases, it was assumed that the cost of the battery storage would be amortized over 6 years.
‡Based on 110000 kWh/year.

Table 25.7. Cost of supplying cooking fuel, lighting, mechanical power, and electricity by biogas.

Base data	
Cattle dung	10 kg/day per cow
Biogas production (at 0.06 m^3 per kg of dung)	0.6 m^3/day per cow
Energy content of biogas as 60 per cent methane*	6.4 kWh/m^3
System lifetime	20 years
Conversion efficiencies	
Internal-combustion engine‖	25 per cent
Electrical generator	90 per cent
Plant cost	
Single-family plant (3 m^3)	6000s
Financing costs†	
Single-family plant, 6000s at 10 per cent for 20 years	705s/year
Engine/generator to provide 1 kWh/day, 5400s‡ at 10 per cent (5 hour/day)	5940s/year
Engine to provide 1 kWh/day, mechanical energy, 3200s‡ at 10 per cent (4 hour/day)	3520s/year
Energy costs§	
Cooking and lighting directly by gas (20 kWh/day)	0.10s/kWh
Cooking and generation of electricity at 1 kWh/day	18.2s/kWh
Cooking and generation of mechanical power at 1 kWh/day	11.6s/kWh

*Approximately 4 kWh of biogas energy is available daily from each cow.
†Based on amortization of loan in equal yearly instalments.
‡Retail costs, Dar-es-Salaam, August 1977.
§Cost of energy production only—does not include cost of appliances or cost of collecting dung.
‖Assuming peak loading.

for more than 5 hours daily, the cost per kilowatt-hour could be reduced by as much as a factor of 4 or 5. That is, with load factors greater than 0.2 (5 hours' use per day), the cost of electricity production by small-scale hydropower systems of the type considered would approach 0.1 to 0.2s/kWh.

Biogas generation. The generation of methane from human, animal, and agricultural wastes is a process that is finding more and more use in developing countries, as people grow more aware of the potential of these 'waste' materials as a source of both energy and fertilizer.[11] Indeed, several biogas plants are operating in Tanzania, and a body of experience in their construction and operation is being accumulated.[12] Thus, it was natural for the workshop participants to consider the use of biogas not only for village lighting and cooking, but for the generation of electricity or mechanical power. For this exercise, the use of cattle dung was assumed, with average production rates and methane concentrations. Furthermore, lighting both by a gas-mantle lantern and with generated electricity was considered. The calculations are outlined in Table 25.7.

Analysis of the data shows that gas requirements for cooking three times a day are approximately 1.4 m^3/day per family, which could be supplied by dung from three to four cows. In contrast, to supply the electric lighting needs of a family (1 kWh/day) by using the biogas to operate an engine-generator set would require heat energy of 5 kWh/day, which could almost be supplied by one cow. This method of lighting, therefore, is almost four times as efficient, in energy use, as a gas-mantle lantern, albeit requiring a much greater capital investment. Finally, this same amount of gas—the gas supplied by one cow—would provide mechanical power alone at 1 kWh/day.

Another potential use for biogas, as a replacement for wood and charcoal, is in firing clay pottery used for water and cooking

Table 25.10 Cost of supplying electricity from existing grid

Base data	
Grid voltage	33 kV
Distance from grid to village (assumed)	20 km
Distribution voltage to substation	11 kV
Local distribution voltage	400 V
Number of substations assumed*	45
Average hook-up distance for 45 substations and 300 families in 16-km² village	0.2 km
Fixed costs	
High voltage step-down transformer	
33 kV to 11 kV, 500 kW at 10000000s/500 kW	1000000s
11-kV transmission line 20 km at 500s/km	10000s
Substation transformers	
11 kV to 400 V, 50 kW at 10,000s/50 kW	450000s
Local distribution lines (400 V); 300 families at 0.2 km per family and 12s/m	720000s
Fixed costs	2180000s
Financing† costs	
2180000s at 10 per cent for 20 years	256000s/year
Cost of electricity‡	
Total annual capacity 500 kW × 8760 hour/year	4380000 kWh
Unit cost of capacity (load factor = 1)	0.06 s/kWh
Unit cost at 10 per cent load factor	0.58s/kWh

*Because local distribution is so expensive, in this example it is cost effective to underutilize the substations by using many of them to reduce local hook-up distance.
†Based on amortization of loan in equal yearly instalments.
‡This calculation represents the unit cost of transporting electricity from the 33 kV transmission line to the consumer. It does not take into account maintenance costs for the system nor the cost of electricity delivered to the point where the 11 kV line starts.

transmission lines to cover the country to the extent of coming within 20 km of every village, or constructing distribution systems to villages within 20 km of present transmission lines. In view of the overwhelming cost of the first alternative, serious thought was given only to the second. On this basis, it was assumed that a village of 300 families would occupy about 16 km² at a distance of some 20 km from a 33-kV transmission line. A summary of the analysis is given to Table 25.10. Transmission line costs (33 to 11 kV with a transformer of 500 kW) and substation (11 kV to 400 V at 5 kW) costs and connection costs came to an estimated total of about 2.18 million shillings. Financing costs, based on a 20-year life for the system, and a 10 per cent annual rate of interest, would be about 256000s per year. If this system were fully utilized (that is, load factor of 1.0) the unit cost would be 0.06s/kWh. Usually a grid system is poorly matched to village needs, however. In the case considered, for example, a village of 300 families has a 500 kW supply continuously available, much more than it can reasonably use on a continuous basis. A more reasonable load factor to assume would be 0.1, which would make the transmission costs 0.58s/kWh. With the average generating cost in the existing grid 0.30s/kWh, the cost for delivered electricity by this scheme would be 0.88s/kWh—a figure comparable to current consumer prices in Dar-es-Salaam. This modest cost, it must be remembered, would be available only to those fortunate few villages within 20 km of the existing grid assuming, of course, that TANESCO would be willing to sell electricity to the distribution point for its cost of generation.

Table 25.11. Cost of supplying electricity by small-scale diesel generators

Base data	
Operation	5 hour/day
Useful life (about 10 years)	20000 hours
Fuel consumption	0.35 litre/kWh
Overhaul	every 5000 hours
Fixed costs	
Retail cost, 6-kW diesel generator	29000s
Overhaul costs	15000s
Installation	2900s
Annual costs	
Equipment and installation, 32000s at 10 per cent for 10 years*	5200s/year
Overhaul, 15000s at 10 per cent for 3 years*	6000s/year
Maintenance, operator	7000s/year
Total annual costs (less fuel) (approximate)	18000s/year
Cost of electricity	
Total energy generated annually	11000 kWh
Unit cost, less fuel	1.6s/kWh
Fuel cost, at 2s/litre	0.7s/kWh
Total unit cost	2.3s/kWh

*Based on amortization of loan in equal yearly instalments.

A more realistic estimate would take into account the cost of transmission to the distribution point, but this information was not available to the panel.

Small-scale diesel generation. In view of the ubiquity of diesel electric generators, it is instructive to examine the cost of generating electricity by this technology. Table 25.11 summarizes the cost figures based on current retail prices in Dar-es-Salaam. At a cost of 2.3s/kWh for diesel-generated electricity, it is apparent that, with the exception of photovoltaics at present prices and biogas-generated electricity, the alternative technologies considered in our discussion would be preferable on a unit-cost basis. Even photovoltaic devices will be preferable in a few yeers.

One of the problems with such solar energy technologies that depend on wind or sunshine or even flowing streams is that these are intermittent sources of energy, so that in the United States they require a back-up system based, for example, on gas, oil, or electricity. The cost of the solar-based system plus the back-up system may be prohibitive. However for many village tasks in the developing countries, the back-up system may be the traditional energy system. If the wind fails to pump water, the villagers simply revert to carrying it on their heads. If the sun fails to shine to refrigerate fish, they are smoked over a wood fire, and so on. Moreover, a number of tasks can be performed whenever primary energy is available—for example, grain can be ground or water pumped and then stored for later use.

Thus far we have established that there are good technologies, that there is preliminary evidence that some of them may be cost effective and that, in many cases, there is a ready back-up system that entails no capital costs. But there is still very little experience with installing such technology in rural villages of the Third World under circumstances where good cost and performance data have been kept. In fact, many of the experiments in placing technology in villages have ended in failure. A number of windmills and a few methane digesters have been tried in African villages, for example, with far from encouraging results. Outside technicians came into the