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BIOENERGY FOR THE SUDAN

REPORT

of a

RECONNAISSANCE VISIT

by a

TEAM REPRESENTING

the

BIOENERGY SYSTEMS and TECHNOLOGY PROJECT

OFFICE of ENERGY

of the

BUREAU of SCIENCE & TECHNOLOGY

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I. Summary of Findings

We conclude that some biofuels, not now considered significant elements in Sudan's energy future, can become important new sources of energy for development applications if appropriate actions are taken to develop them; others are of doubtful significance and warrant little or no consideration at this time. This report gives our views of the most promising bioenergy options and suggests ways in which BST, working through AID/Khartoum in conjunction with its energy project activity, can assist the GOS to pursue one or more of the options listed in the recommendations section.

II. Background of Bioenergy Team Visit and Report

The crucial dependency of future national development in Sudan on a stable energy supply system has received wide recognition. As early as 1979, A.I.D., both S&T/EY and the Khartoum USAID Mission, began to emphasize the key role of energy in Sudan. One of the first A.I.D.-financed energy activities in the Sudan was a National Energy Assessment funded under the Energy Policy and Planning Project of S&T/EY. This effort involved training GOS energy professionals, building the planning capacity of the GOS National Energy Administration (NEA), and working with the NEA to assess national energy needs and potentials. A major component of that Assessment is concerned with renewable energy, primarily biomass and hydropower. This bioenergy team has been financed by USAID/Khartoum and AID/W S&T/EY to assist the NEA in defining the position bioenergy can occupy in National Energy Planning. The team's recommendations owe much to work of both NEA staff and EDI consultants, notably Constantine Salame.

This report differs from the one envisaged in the cable (State 024082 of 29 January 1982) outlining a scope of work for the Bioenergy Systems and Technology (BST) Project team requested by the AID Mission (Khartoum 11572 of 28 December 1981). The original scope of work called for this team to gather and analyze data on a wide range of subjects related to bioenergy. On our arrival in Khartoum, however, we learned that most of these tasks had already been accomplished by others. Moreover, the National Energy Administration (NEA) is in the process of incorporating available data on biomass resources into a comprehensive overview of Sudanese energy problems and opportunities. On the strength of this previous work, we have been able to focus on those biomass materials which are already important energy sources (fuelwood and charcoal) and those which NEA considers to be potentially important in the near future (surplus molasses, crop residues, and water hyacinths). On the basis of available documents (furnished by NEA and listed at the end of this report), discussions with officials of the government of Sudan (GOS) and USAID, and observations of field trips, we have considered alternative technologies for converting each biomass material into fuel(s) which -- by substituting for petroleum-based fuel -- might alleviate the present burden on the Sudanese economy of high energy costs. We have examined the potentials for biomass energy in the context of Sudan's urgent need for new sources of energy, its national goals for developing and modernizing the agricultural sector, and the environmental dangers posed by unmanaged exploitation of natural resources.

III. Bioenergy - The Existing Situation

Bioenergy is at present the main source of energy for the Sudan. It comprises [illegible]ut 85 to or about 270 PJ (PJ=10^{15}J) of a total national energy usage of about [illegible] PJ (Kyle, 1981). The main form this energy takes is fuelwood and charcoal. It [illegible] been estimated that about 10.9 million tonnes of fuelwood are burned directly each year, while another 3.2 million tonnes are turned into 550,000 tonnes of charcoal and then consumed, (Yassin, 1981). Some of these fuels are used in such industries as bakeries or brickmaking, but over 90% is used directly for household cooking.

For a nation of about 20,000,000 people, this means a per capita consumption of about 3/4 of a metric ton of these fuels every year, and indeed a recent household survey (Tageldin Ali and Yasin, 1982) has shown the per capita use in Khartoum Province for fuelwood is 0.7 mt, and 0.1 mt for charcoal.

Can the Sudanese forest resource support this usage? According to somewhat old figures -- at present being revised -- there are approximately 46,000,000 hectares of forested area in the Sudan (Tageldin Ali and Yasin, 1982). The total growing stock of wood is calculated at 447 million tonnes. Out of this stock, and allowing for losses from fire, clearing, and so on, there should be an allowable annual cut of 17.33 million tonnes.

Such an annual cut apparently leaves a small margin for supplying present Sudanese wood fuels needs. However, it has been pointed out (Mukhtar, 1978) that two basic problems arise: one has to deal with future trends and the other with regional disparities. The future trends involved are: (a) population growth and (b) expansion of forest clearing for agriculture. The population of the Sudan is growing at about 2.7% per year (Kyle, 1981).

According to some projects, the per capita usage of wood fuels is also growing (Mukhtar, 1978): from 0.66 tonne in 1962 to 0.73 tonne in 1978. All these factors would result in a continuation of the rise in total consumption of wood fuels (7.1 million tonnes in 70/71 and 14.1 million tonnes in 79/80) to a total of 22.9 million tonnes in 89/90 (Yassin, 1982).

In addition to this rise in demand, there are factors present that will tend to depress supply. Combined losses from introd[illegible]ing mechanized agricultural schemes, from slash-and-burn agriculture, and from ov[illegible]rgrazing are estimated at 1.2 million tonnes of wood a year (Tageldin Ali and Yassi[illegible], 1981).

The regional disparity is the problem of most economic interest at present. Fifty seven percent of the forested area lies in the southern region, which has only 27 percent of the population, while another 12 percent lies in the eastern region, with only 9 percent of the population. The more arid areas to the north and west, including the capital Khartoum, often have to bring in fuel supplies from long distance. In the case of Khartoum, these distances run upwards of 200 miles for fuelwood hauls and 350 miles for charcoal (Badi, 1982). They can also lead to the vicious feedback mechanism of over-cutting in semi-arid areas and the consequent destruction of local wooded areas.

The regional problem shows up in high transport costs and in high prices to users in Khartoum, for example. Between 1976 and 1979, transport costs for fuelwood to Khartoum rose by 96 percent, and for charcoal, 67 percent (Yassin, 1981). This has been reflected in rises in consumer prices for woodfuels. Fuelwood in Khartoum costs S.£* 36/tonne in 1979 and is now reported to cost S.£ 67/tonne (Badi, 1982), while charcoal prices over the same period have risen from S.£ 66/tonne to S.£ 144/tonne. According to one survey (Tageldin Ali and Yassin, 1981) this makes the cost of 1000 kilocalories a net energy delivered to an end use such as cooking slightly larger for fuelwood users than for kerosene users, and significantly more expensive for charcoal users.

What ongoing steps are being taken to solve this situation? Sometimes, unfortunately, positive policies are enunciated but not carried out. For example, in the Gezira agricultural scheme area, 5% of the area was supposed to be dedicated to forests. In fact, much less of the area is actually in trees. (Baldi, 1982). Often the difficulty is money. In 1976/1977, total investments in Sudan forecasts were S.£ 2,895,000 (Mukhtar, 1978). However, the estimated costs of a 12-year program to enrich Sudan's forests to insure a continuous supply was set by one projection at S.£ 33,400,000 while a modernization of the present wasteful primitive methods of charcoal-making would call for an 8-year, S.£ 29,785,000 program (Yassin, 1981). All this means that there is often not enough money to plant or replant trees, nor enough to thin them out and otherwise take care of later maintenance. At the same time, existing sources of revenue are not adapted to desirable policy goals: royalties are now collected by the government from all charcoal-makers. However, since the royalty is measured by the quantity of charcoal produced -- not by the wood consumed -- there is little motivation to invest in improved charcoal kilns.

The other main source of biomass presently used for energy is agricultural residues together with animal wastes. Unfortunately, there are no data on how much waste is used for what purposes -- except that cotton wastes are supposed to be burned to prevent the spread of plant disease. It has been reported that animal wastes are not uncommonly used as fuel in the Gezira Province. However, it has also been observed there that crop wastes are used for animal fodder and for building materials there. It can be calculated theoretically (Salame, 1982) that the total wastes that might be avilable for energy amount to almost 300 PJ, but whether these wastes are available at zero opportunity costs -- even neglecting the collection problem -- remains an open question.

Other special wastes and residues could be used for bioenergy, but are not so at present. Such forms as banana stalks, molasses, and water hyacinth will be considered below.

IV. Bioenergy Opportunities

The following are some of the bioenergy opportunities identified by the team, based on previous National Energy Administration work and on their own investigations.

In summary, they are:

1. Ethanol Production from Molasses
2. Charcoal Production from Banana Residues

3. Fuel Briquetting of Agricultural Residues
4. Biogas from Water Hyacinths and Animal Wastes
5. Improved Charcoal Kilns
6. Afforestation of the Banks of the Reseires Reservoir
7. Afforestation in Khartoum Province
8. Wood or Gas Production from Shelter Belts in Norther Sudan

These opportunities are described in more detail below.

1. Ethanol Production from Molasses

The Sudan is actively promoting its sugar industry. Molasses, a byproduct of this industry, can be fermented into ethanol and used as an additive to or a replacement for gasoline. This possibility has been succinctly summarized by Salame (memo of March 31, 1982).

The amount of molasses produced in 1979/1980 by the sugar industry was 64.6 thousand tonnes. By 1983/1984, when the large Kenana sugar facility is to be operating at full capacity, total output of molasses should be 214.5 thousand tonnes. There are various possible uses for the molasses. One possibility is for feeding cattle, and indeed some 5,000 tonnes are reportedly now utilized by local cattle. However, much of the cattle in the Sudan is nomadic, and much other cattle that could use feed supplements are located at long distances from the sugar-producing region. Another possibility is to sell the molasses on the world market. However, at present the only way of reaching the world market is Port Sudan, the cost of transportation from the sugar region to Port Sudan is relatively high, and at present depressed world prices (recently $ 55/tonne), it does not pay to export molasses.

In default of any present viable outlets for molasses, sugar companies have been dumping it in local water bodies. However, molasses is sufficiently chemically active that it acts as a potential danger to the environment. Recently the Kenana Sugar Company has considered the desperation measure of paying a molasses firm $ 10/tonne to haul it away.

Under these circumstances, the ethanol alternative appears attractive on an priori basis. There is no great hurdle to the use of ethanol, either in the chemical industry or in motor fuel. It has been well established in countries such as the United States and Brazil that alcohol can be mixed with gasoline in proportions up to 10-20% with little change in engine performance. Ethanol can also be mixed with diesel fuel as a "stretcher" under certain circumstances or can be burned in a pure state if some adaptation of conventional internal combustion engines is made.

Under proposed schemes, molasses would be fermented by yeast in the classical way. In addition to producing alcohol, other valuable byproducts would be produced, for example, yeast. Furthermore, the stillage or residue of the fermentation process can be converted into valuable methane by means of an additional anerobic fermentation step.

A possible stumbling block to such a scheme is the need for energy in the form of steam and electricity during the fermentation process. While the present energy needs of the sugar refineries can be met by burning the bagasse or crop residue -- and in the case of Kenana in the process also generating electricity to sell outside -- it is not certain whether enough bagasse would be available for the molasses fermentation process. Indeed, in an ethanol feasibility study carried out for Kenana (ABA, 1980), it is assumed that fuel oil would be needed to provide steam for the process. Obviously, the use of petroleum in the process would reduce the energy advantages of the project.

In the model assumed by Salame (see above), a sugar firm would convert 160,000 tonnes of molasses a year into 49.6 million liters of ethanol, with byproducts of 1690 tonnes of yeast and 67.2 billion kilocalories of methane. Total yearly revenues from these products -- at present oil prices -- would be respectively, $14.6 million, $0.7 million, and $1.3 million, for a total of $16.6 million annually.

On the cost side, capital costs of $31.8 million are assumed, spread out over a contruction period of three years. Assuming that the weighted average amount invested during those years would be $17.3 million, at 10% per year interest, an additional charge of $5.2 million should be made, giving a grand total capital cost of $37 million.

To calculate the percentage return to this capital, one must subtract from the $16.6 million revenues both an operating and maintenance cost estimate of $10.4 million and a sinking fund cost (assuming a 20-year plant life) of $1.59 million, to give a net profit of $4.61 million. This net profit represents a 12% return on capital invested. It roughly corresponds to the 14% return assumed by the earlier feasibility study done for Kenana (ABA, 1980).

What effect will rising oil prices have on the profitability of such a venture? If oil prices rise at a real rate of 3% yearly -- as promised in some OPEC pronouncements -- than eight years after the beginning of construction, revenue from ethanol should increase by $4.38 million, thus possibly increasing the return to capital to 24%. However, it must be cautioned that this result follows only if petroleum is not used in the production process. In case it is, O & M costs will also rise and net returns to capital will fall somewhat between 12 and 24%.

It is of some interest to note that the Kenana Sugar Company is studying the ethanol alternative, together with other ways of solving the molasses problem.

2. Charcoal Production from Banana Residues

The waste products of the Sudanese banana industry are at present not utilized for any useful purpose. Salame (memo of April 5, 1982) has sketched out the possibility of installing modern charcoal kilns at banana plantations to produce useful energy from these residues. The banana stalks and other residues in this scheme would be first sun-dried for a month, and then converted to charcoal.

The main cost factor would be the cost of building masonry kilns, which can be estimated at S.£ 3000 each. It is envisaged that 36 such units could be installed on various plantations, at a total cost of S.£ 108,000, and produce 3,200 tonnes of charcoal annually. Assuming charcoal prices of $130/tonne, revenues would be S.£ 421,200 per year. Obviously, even adding in operating and maintenance and transport costs, such a venture promises high financial returns (see Salame, quoted above). The amount of energy generated, however, being just 0.096 PJ is fairly modest compared to national energy consumption of over 300 PJ (PJ = 10^{15}J).

3. Fuel Briquetting of Agricultural Residues

Fuel briquettes that could be used either in rural households or in industrial boilers can be made by compacting agricultural residues with some liquid substance (see Salame memo of April 6, 1982). Since the total amount of agricultural residues is large, there is at least the theoretical possibility of converting large amounts of bioenergy to this form.

The process of briquetting involves collecting the residues and then either chopping or screening them to produce particles of sufficiently small size. Then they must be dried, preferably by natural processes, in a place protected from rain. They are then mixed with binding materials such as animal wastes or molasses. Finally, they are compressed to briquette form in a mechanical press.

Briquettes have the advantage of easier handling, transportation, and storage qualities, plus improved combustion characteristics for more controlled heating. It is presumed that markets could be found for them, although even cheap briquettes would have to complete with gathered residues and fuelwood use in rural areas. Indeed, one effort to sell briquettes to urban bakeries and brickmakers resulted in failure.

The sum total of agricultural residues is very large. According to the calculations of Salame (see Table 1), the total potential energy available -- even when other uses are allowed for -- is very large: some 296 PJ (PJ = 10^{15}J). However, it must be pointed out that the estimates of total residues are extrapolated for Sudanese crops from Egyptian studies. Furthermore, the figure for the "available" proportion of residues has little if any empirical backing. Residues serve many purposes: fuel, animal feed, fertilizers, and construction materials. Some residues, such as groundnut shells, are available at processing plants. But, with the general scarcity of all such resources in rural Sudan, there is some question as to whether a large fraction of all agricultural residues is available for new energy uses. And if they are, what institutional measures are going to be used to set up a collection, transport, and processing system?

Costs of briquetting vary by the size of plant. A small 1.14 tonnes/day plant could cost S.£ 1350, but its output could displace S.£ 33,150 worth of charcoal. A larger, 1.33 tonnes/hour plant would cost S.£ 1,277,000, but could displace yearly S.£ 837,200 worth of charcoal or -- depending on compatibility of end users, some S.£ 635,000 worth of fuel oil. In the latter case, however, since operating and maintenance costs are estimated at S.£ 709,000, the project would pay only when and if oil prices rise in the future.

4. Biogas from Water Hyacinths and Animal Wastes

Water hyacinths are a prominent nuisance plant in the waters of the White Nile in the Sudan. They can, especially in conjunction with animal wastes, form the substrate for an anerobic digestion process that produces biogas, a mixture of gases containing approximately 50% methane.

There is a vast potential supply of water hyacinth. This weed is controlled in some parts of the Sudan by chemical means, but in other places is removed mechanically and then burnt. According to Salame (memo of April 10), 300 - 500 thousand cubin meters of water hyacinth are now removed every spring from the White Nile. As far as animal wastes are concerned, it is true that many of the cattle in the Sudan are herded under nomadic conditions, but fixed supply areas like dairy farms in the Khartoum region could produce some 275,000 tonnes of animal wastes per year. The high water content of the water hyacinth plus the "pre-processed" characteristics of animal wastes should make the combination a good feedstock for biogas units. However, water hyacinth collection would have to be carried out year-round, not seasonally as at present.

Biogas technology is by now well established, especially in India and in China, where the gas is widely used for rual cooking and lighting. However, the system does require a consideration capital investment and a degree of maintenance, even at the level of small individual - family digesters. For larger community units, management of digesters and distribution of gas can be a problem.

Costs for biogas digesters vary widely, depending on type of materials and amount of local labor used. Salame assumes a capital cost of S.£ 1000 and operating and maintenance costs of S.£ 50 a year. If the gas produced is valued at its replacement value for charcoal, revenues would be S.£ 295 annually, giving a good rate of return on capital. This analysis contrasts with another study of the water hyacinth problem (von de Goltz and Perwanger, 1980) which concludes that the biogas digesters being tested at that time had serious technical defects and that biogas was not economically feasible, especially for a poor rural population, under prices for alternative energy sources then prevailing.

5. Improved Charcoal Kilns

The use of improved, concrete charcoal kilns has been considered above in connection with use of banana plantations. Such new types of kilns could also be used in reserved and other forested areas to increase the efficiency of charcoal production. Such a scheme, however, runs into several types of non-technical problems.

In the first place, who is to produce the charcoal? Under the present system, this is all carried out in the private sector, and the private sector has several reasons for not wanting to change to more expensive, if more efficient kilns. As pointed out above, the government royalty system taxes charcoal rather than wood to make charcoal, so a good deal of motivation for more efficiency is lacking.

Even if this last problem can be overcome, the difficulty arises that forest stands suitable for charcoal in the Sudan often turn out to be relatively small. In such a case, the construction of a large permanent kiln is not satisfactory. It is evident, however, that portable metal kilns could be -- in fact, have been -- introduced. However, the difficulty with portable kilns is they are relatively small: primitive kilns now used produce on the order of 3,000 tonnes of charcoal at one firing. It is indeed reported that experiments with portable kilns have been failures.

All in all, unless forest policy changes, the introduction of more efficient kilns seems to be an unpromising option for the Sudan.

6. Afforestation of the Banks of the Roseires Reservoir

The Roseires dam is a major source of hydroelectric power in the Sudan and makes possible the irrigation of many hectares of farmland. Unfortunately, siltation in its reservoir is proceeding five times as fast as anticipated. The formation of a silt island near the sluces even led once to a temporary sudden loss of its 65 MW of power.

Efforts to solve this problem have included proposals to raise the height of the dam by 10 meters. An alternative that could be more permanent and that involves the production of bioenergy is to afforest the banks of the reservoir.

At present, the banks of the reservoir, including the drawdown zone, are farmed extensively with annual crops. After harvest time, these cropped areas provide little soil retention characteristics, and it is believed by staff of the Forestry Administration that this phenomenon is one of the major contributors to the siltation problem.

As an alternative to forest land use, the banks of the reservoir could be planted with water-compatible tree species such as Acacia nilotica. Such plantings would not only help soil retention, but they could be harvested to help in the severe fuelwood and charcoal supply problem now plaguing the Sudan.

There is at present little data on the costs and benefits of such a program. However, pilot plantings, under the aegis of the Forestry Administration, are just now getting underway. It is roughly estimated that plantings could be carried out for about S.£ 200 per hectare, with yields of wood yearly expected of about 30 m^3 or 12 tonnes per hectare (Badi, 1982). If we supposed that averaged yearly costs were about S.£ 100, then costs per tonne would be about S.£ 8, or about S.£ 0.40 per GJ ($GJ=10^9J$).

7. Afforestation in Khartoum Province

Since fuelwood supplies for Khartoum typically arrive from great distances nowadays, it would be highly desirable to grow more wood locally. The primarily problem with this option is that the available land is quite arid. This difficulty has been studied in the context of providing irrigation water for the growth of species such as encalyptus. The cost of irrigation can be quite high, however, and the economic feasibility of such a project is questionable.

An alternative scheme has recently been informally proposed (Badi, 1982). It is believed that drought-resistant species such as mesquite can be successfully grown in many unused areas of Khartoum Province. The survival and maturation of such can be aided by constructing inexpensive rain catchment basins at strategic locations.

A cost-benefit analysis of such a scheme has not been carried out. However, it is believed that capital costs might fall in the range of S.£ 175-225 per hectare. Yields of wood might be as much as 20 m^3 per hectare (Badi, 1982). If we suppose that yearly costs are about S.£ 100 per hectare, and yields are 8 tonnes, then costs per tonne of wood would be about S.£ 12, or some S.£ 0.60 per GJ ($GJ=10^9J$).

8. Wood for Gas Production from Shelter Belts in Northern Sudan

Agriculture in northern Sudan has long been plagued by the problem of dusty winds and sand creep or encroachment. In fact, in recent times, there has been much abandonment of farms in the Northern Province. A solution to this problem has been sought through providing shelter belts of trees to mitigate wind action. A joint Canadian-Sudanese pilot project of this sort in the Kerma Valley has recently been completed (Masnad, 1981). The benefits from this program have included reduction in wind speed, a rise in soil temperature, and a decrease in air temperature.

The original purpose of the belts was to create a better micro-climate for agriculture. However, the Forestry Administration has recently experimented with wider, "production plots" of species like eucalyptus that are especially suitable for wood production in the same area. Those trees are irrigated by methods similar to those used in the original shelter belts.

The possibility exists for enlarging and spreading this program to other areas. The wood obtained from the plots can be used locally for building purposes or as fuelwood. Alternatively, the harvested wood can be gasified -- either directly or through a charcoal stage -- and the gas can be used to replace the expensive diesel fuel used in most local irrigation pumps.

The costs and benefits of such a wood-producing shelter belt scheme have not been analyzed. However, the average yearly costs of the pilot shelter belt program were S.£ 20,400 for an area covering 190 hectares. This makes an average cost per hectare of S.£ 107 annually. Yields from wood produced are also not known. However, yields would be relatively low, because of the growth-inhibiting effects of th local climate that were noticed in the pilot program. Furthermore, cutting might have to be reduced to sustain the shelter-belt characteristics of the scheme. However, if we assume a yield of only 5 m^3 or 2 tonnes per hectare per year, then the cost of wood would be S.£ 53.5/tonne. This cost is high compared to costs in Khartoum, but would almost certainly be locally competitive. Furthermore, the annual costs may well be overstated, since the pilot program included much scientific instrumentation and monitoring that would not be necessary in production practice.

For evaluating the use of such wood in local gasifiers, it should be noted that the cost per GJ (GJ=10^9J) is about S.£ 270. To this would have to be added the capital charges and operating and maintenance costs of the gasifiers. In making this comparison, the cost of the diesel fuel now used chould be taken into account. Currently, diesel fuel costs S.£ 7.70 per GJ in Khartoum and is presumably considerably higher in remote areas in the North.

V. Recommendations for Bioenergy Development

In the Sudan, bioenergy has already begun the transition from a traditional pattern of use to become a component of the national commercial fuel market. However, the significance of the bioenergy sector, among other energy sectors, is even greater.

The bioenergy sector is interrelated with other energy sectors in several ways. The transport of firewood and charcoal consume 8% of the national use of diesel fuel. The cost of this conventional fuel transport represnts a major portion (as much as 5%) of the cost of charcoal delivered to a major market such as Khartoum. The 65 MW hydro-electric generating capacity of the Reseires Dam is threatened by siltation which many GOS forestry authorities have attributed to insufficient tree cover in the dam's catchment. The lack of local tree cover is due in part to the firewood and charcoal market of Khartoum (hundreds of miles distant) and in part to the rapid spread of energy intensive mechanized rainfed agriculture.

The complex set of interrelationships between agriculture and bioenergy has been discussed in Section III. The GOS National Economic Development Policy emphasizes increasing exports of agricultural products and building of indigenous oil production capacity. These policies have received substantial donor support, including both AID and the IBRD. The urgency of effort being expended on these two sectors, pressed on by the severe balance of payments, has precluded serious consideration of the bioenergy sector. This is in spite of concern expressed by many for the stability of agriculture and environmental conditions - that could be alleviated by afforestation programs. The following set of recommendations are based on criteria derived from these national priorities; namely, the easing of the balance-of-payments deficit and the stimulation of the agricultural sector (see Appendix A). Similarly, the selection of sites for and design of specific programs is guided by a consideration of the environmental consequences of both agriculture and forestry.

Recommendation I: Gasifiers and Irrigation

Case #1 - Shelter Belts

The NEA should explore the feasibility of the use of gasifiers for irrigation pumping. The economics of the use of gasifiers for the reduction of diesel fuel needs for irrigation pumping seem to be attractive. In drier areas such as the Nile Province it has been proven financially attractive to grow shelter belts of a variety of trees under irrigation. In that project one of the key constraints was (and is)

the shortage of diesel fuel for well pumps. This shortage affects the productivity of agriculture even more severely. A linkage between use of gasifier-powered irrigation pumps and increased agricultural productivity could contribute further to the acceptance and spread of the shelter belt program, which if successful further aids agricultural productivity by the forestalling of desertification.

The technical feasibility of using gasifiers in this area depends upon the size, age, and design of existing pumps. Older and larger (more than 150 hp) diesel pumps are more likely to be easily converted to use producer gas in a mixture of up to 70% producer gas and 30% diesel fuel. The wood can be used directly as a feedstock for the gasifiers, or it can be converted to charcoal. Conversion to charcoal lowers the overall energy efficiency, but improves the ease of gasifier operation and maintenance.

There are two issues of major concern: (1) the management of the shelter belts to meet both need for shelter and fuel needs, and (2) the ability of local mechanics to maintain the gasifiers. To these two issues should be added the overall economics of such gasifier powered irrigation pumps.

Case #2 - Large Irrigation Schemes

The use of gasifiers in these schemes face a different set of economic and resource constraints. In general diesel fuel is more regularly available and is cheaper because the transport infrastructure is better. However, these are still a significant cost savings (and fuel savings) from the use of a local fuel as opposed to an imported fuel.

On the resource side there are many more competing demands for the wood than in the shelter belt case. In these schemes there are many traditional industries such as bricks, bread, etc. which consume firewood or charcoal - thus the market study for use of gasifier powered irrigation pumping in schemes such as Gezira, or others in the White Nile or Blue Nile provinces must be done carefully to ensure that charcoal is available at a price competitive with diesel.

The problems of maintenance are less likely to be severe in these schemes with their relatively well developed infrastructure. There is even the possibility of local fabrication of simple designs of gasifiers.

Many of these schemes have large numbers of pumps (El-Nayal et al. 1972) and a thorough analysis must be made of the age and size distribution of the pumps to determine the approach to a prototype gasifier project that is likely to have the most impact. A preliminary analysis indicates that while larger pumps constitute only one third of the total number of pumps, they may represent as much as three-quarters of the total pumping capacity. See list of pumps in Appendix C.

Perhaps the major issue is the opportunity cost of land use in such schemes. There is no complementation as in the valuable use of the tree planting as shelter belts to help the overall economics.

Recommendation 2: Fuelwood and Charcoal.

Wood and charcoal presently are Sudan's most important forms of bioenergy, and will remain so in the forseeable future. However, as demand for these fuels continues to increase tree numbers are decreasing. If these trends continue unchecked, these fuels will become too expensive for many Sudanese and deforestation will lead to irreparable damages to the fragile environment in much of Sudan's vast semiarid and arid regions.

We believe that a massive tree-planting program should be a high priority item in any bioenergy initiative of GOS. Increased management of forests will be needed in the near future to avoid a fuelwood shortage. Efforts to promote more efficient use of existing supplies (new cookstove designs, improved methods of making charcoal, etc.) can help slow the rate at which a crisis will arrive but they are palliatives. The primary need is, and will remain, to increase the number of trees from which future supplies of wood and charcoal must come.

Massive afforestation and reforestation is essential, not only to meet energy needs, but also to protect Sudan's water and soil resources. Watershed protection, including reduction of siltation in reservoirs for irrigaton and hydroelectricity (cf. Roseires dam) is a vital role trees can play in protecting Sudan's few waterways. "Shelterbelts" of trees planted to protect cultivated fields and urban areas alike perform invaluable services in areas where hot, dry winds endanger crops and livestock and inconvenience humans. Unfortunately, numerous large-scale, mechanized dryland farming projects (meant to increase export earnings by producing cash crops for sale abroad) are supplanting natural forests and plant communities in semiarid regions: changes in the approach to agricultural development must be made if the nation is to avoid large-scale desertification.

The establishment of carefully planned bioenergy projects that are linked to secure, well-managed supply of uniform quality firewood or charcoal will help to advance GOS goals of afforestation. While we believe that the efforts of the Forestry Department to formulate programs to meet present and future firewood needs deserve support, we also feel that there is a need to explore other ways to encourage afforestation. There are many examples of bioenergy projects in countries such as Brazil and the Philippines where clear linkages are established and maintained between firewood plantations and gasifier projects or direct fired boilers. These integrated bioenergy projects are also linked to increased agricultural productivity thus achieving high visibility among reforestation efforts. Indeed establishing this sort of linkage may provide a key new point of entry for restructuring the GOS's approach to reforestation and management of degraded forest lands.

NOTE: The Beijer Institute of the Royal Swedish Academy of Sciences has conducted an exhaustive analysis of the fuelwood situation in Kenya, on the basis of which a program of action has been proposed for consideration by the Government of Kenya. While Sudan and Kenya differ in many ways, fuelwood is vital to both, and they have comparable needs. In our visit to Khartoum we did not gain the impression that Sudanese officials were in close contact with Kenyan counterparts. We suggest that NEA and Sudanese forestry officials might profit from studying the Beijer report and its fate in Kenya.

Recommendation 3: Surplus Molasses

Our knowledge of this situation is too sketchy to offer any but very preliminary comments. We understand that molasses is in surplus at all of Sudan's sugar mills and that it currently has a negative value--i.e., it costs money to dispose of it. The question is: can the surplus molasses be converted economically into energy? This question cannot be answered definitively without considering the two alternatives: (a) use the molasses to produce fuel alcohol; or (b) use the molasses as cattle feed. Therefore any study of the ethanol question must be paralleled by a look at anintegrated cattle feedlot operation.

Recommendation 4: Crop Residues

Although crop residues hold little promise as major sources of bioenergy, there are exceptions where large quantities of residues are concentrated at localized sites; in the Sudan, this occurs with peanut (groundnut) shells which accumulate in large amounts at the processing mills where farmers bring their harvested crops. Whole nuts are passed thorugh milling machines which separate the seeds from the crushed shells. According to NEA officials, peanut shells are produced in large quantities each year and have no present use. Can these be converted into usable energy?

We assume that processing plants are powered either by diesel-fueled engines or by electric motors (which are indirectly diesel-powered). If so, then the peanut shells might substitute for the diesel fuel, and thus make the processing plant energy self-sufficient, if the shells were partially combusted in a gasifier. The gasification would yield producer gas (carbon monoxide + hydrogen) which could then be burned in an internal combustion engine in place of diesel or other petroleum fuel. Detailed study will be required to determine the economic feasibility of such systems in the Sudan but there is little question that they are technologically possible and likely to be economically attractive.

Recommnedation 5: Water Hyacinths

The presence of water hyacinths in certain parts of the While Nile creates a navigational problem for transport vessels. Several advisory groups have recommended steps be taken to remove the plants periodically in order to keep open shipping channels; any such operation would have to be coupled with some means of disposing of the harvested plants. An obvious possibility is to use the collected biomass as an energy source -- but how? A German team studied the possibility of the anaerobic digestion of water hyacinths to obtain biogas. They worked with small-scale digestors, apparently visualizing the eventual use of hyacinths as a feedstock for family-sized units. Results were not encouraging and the project was terminated. However there does exist an ongoing Gas Research Institute (Chicago) funded project in Florida at Disney World on the large scale digestion of water hyacinths to supply methane for mixing in natural gas distribution systems. The feasibility of such a scheme should be studied in the Sudan.

APPENDIX A

Criteria for Selecting Projects

Several criteria are useful in judging the merits of the various potential projects discussed above.

First of all, the project must be economic, in that it is profitable, at least in the sense of social costs, and preferably in purely financial terms also. Some projects might be economic only in the future, when oil prices rise or when wood becomes scarcer, but such options tend to be inherently less advantageous than one that brings in sure profits.

Another useful criterion is one of quantity. Projects that promise to produce large amounts of energy may be preferable to those producing smaller amounts. This criterion is especially valid if there is a shortage of managerial expertise in-country or among donor organizations, since it is generally easier to orgaize and implement one large project rather than many varied smaller projects.

Oil replacement and therefore balance of payments is an important criterion for the Sudan, as it is in many developing countries. This criterion would give more weight to projects that replace oil products, either directly by providing substitutes like ethanol, or indirectly, by using charcoal or producer gas to fire boilers or run engines instead of oil.

Other things being equal, projects can receive higher ranking if they contribute other types of benefits to the economy. These benefits can be benefits to other parts of the energy economy, like planting trees to preserve the watersheds of hydroelectric projects. They can be benefits to agriculture, such as shelter belts. Benefits could accrue to transportation, by harvesting water hyacinths along the White Nile or by providing local wood and charcoal and eliminating long truck hauls. Many forestry projects have general environmental benefits, while community-sized projects could produce social benefits.

A final criterion is one of institutional implementability. While it is not always possible to make conclusive plans for implementing energy projects -- once they are out of the pilot plant stage -- it is nevertheless highly desirable to be able to trace which institutions will carry out the practical production of the energy. In the past, many promising energy pilot projects have led nowhere, just because of local institutional incapacities. Often several institutions would be involved, such as when a forestry department plants trees, and the wood is then cut and sold by private contractors. Sometimes, as for ethanol production, the key implementing steps can be carried out by one entrepreneur. In any case, either entrepreneurs or government entitites acting like entrepreneurs, or new collective community entities must become available to make pilot projects into real energy production.

APPENDIX B

Charcoal Cost Calculation

1. Lorry carries 160 sacks, 45 kg each of charcoal = 7.2 tonnes

On an earth road, 50 g gasoil per ton-km is used.
On an paved road, 30 g gasoil per ton-km is used.

Taking 40 as an average, one lorry uses 288 g gasoil per km.

For hauls of 300 km, one lorry uses 86.4 kg gasoil or about 3.62 GJ

For 500 km, about 144 kg used, or about 6.21 GJ.

For comparison purposes: 7.2 tonnes charcoal=216 GJ

APPENDIX C

PARTIAL LIST OF PUMPS IN THE SUDAN

(listed in order of size)

Site	H'power	Yrs left	Feddans	Acres/hp
Blue Nile -- East Bank Sennar				
03		5	500	?
03		5		?
14			300	?
20	36	5		1.1
24	36	5		1.6
19	40	2		1.1
08	42	5	550	2.9
19	49	7	240	1.1
07	55			2.4
08	58	5		2.9
06	67	5	202	1.6
06	67	5		1.6
22	67	5	400	1.4
22	67	5		1.4
05	73	5		2.8
23	77		800	3.3
21	80	5		3.6
02	90	5		2.1
04	90	5	400	2.2
10	90	7		1.8
05	95	5	450	2.8
21	95	5	600	3.6
24	95	5	450	1.6
17	96	2	200	2.2
04	97	5		2.2
08	99	5		2.9
11	134	7		2.5
11	134	7		2.5
07	135	5		2.4
09	135	5	400	3.1
10	135	7	400	1.8
20	135	7	450	1.1
19	138	5		1.1
07	150	5	800	2.4
24	153	5		1.6
22	164	5		1.4
23	174	5		3.3
26	223		500	1.2
26	223	1		1.2
02	225	5	650	2.1

20	238	5		1.1
18	240	7	3120	2.7
18	240	7		2.7
15	300	7	4510	2.1
15	300	7		2.1
15	300	7		2.1
29	325	1	1500	2.2
27	342	7	3840	3.2
27	342	7		3.2
12	360	7	7000	5.0
12	360	7		5.0
12	360	7		5.0
12	360	7		5.0
13	360	7	7000	5.0
13	360	7		5.0
13	360	7		5.0
13	360	7		5.0
25	360	7	5000	2.9
25	360	7		2.9
28	360	7		2.4
28	360	7		2.4
29	380	5		2.2
11	400	7	2800	2.5
30	450	7	2860	3.3
30	450	7		3.3
11	500	7		2.5
28	500	7	2845	2.4
01	530	7	3625	3.5
01	530	7		3.5
27	570	7		3.2
18	705	7		2.7
16	720	7	10005	2.2
16	720	7		2.2
16	720	7		2.2
25	1080	7		2.9
15	1320	7		2.1
16	2610	7		2.2

The total horsepower of this group of pumps is: 23,051

The total number of pumps in this group is: 77

The average horsepower of pumps in this group is: 299

The average expected life of these pumps is (in years): 5.9

Blue Nile West Bank -- Sennar

08		2		?
08		5		?
10		5	120	?
28				?
30				?
01	24	2		2.1
15	28			1.6
02	30	2	120	1.8
01	36	2	120	2.1
09	36	5		3.2
02	40			1.8
19	40		120	3.1
13	42	5		3.8
15	42	1		1.6
16	42	5		2.4
24	42	2	400	2.9
10	47	5		?
21	55			1.7
09	66			3.2
13	66		400	3.8
18	66		650	3.0
18	66			3.0
25	66	10		3.3
05	67	5		2.6
12	67	5	400	2.6
14	67	5	420	6.5
16	67	5	250	2.4
17	67	5	450	3.5
17	67	5		3.5
21	67	5		1.7
25	67	5	1000	3.3
11	77		300	4.0
05	80	5	600	2.6
08	90	5	450	?
18	90	5		3.0
05	95	5		2.6
06	95	5		4.4
09	95	5	600	3.2
12	95	5		2.6
24	99	2		2.9
21	125	5	400	1.7
06	134	5		4.4
07	134	5	1200	2.5
07	134	1		2.5
22	135	5	225	1.7
23	135	5	450	3.5

20	150	5		2.7
03	180	5		2.8
03	180	5		2.8
04	180	2	1205	3.5
04	180	2		3.5
25	180	5		3.3
26	180	5		3.5
15	210	5	420	1.6
20	210	2	1620	2.7
06	240	2	2000	4.4
07	240	2		2.5
20	270	1		2.7
26	270	5	1500	3.5
27	330	5		2.1
03	342	5	2850	2.8
03	342	5		2.8
29	360	7	120	0.3
27	400	5	2500	2.1
27	530	5		2.1

The total horsepower of this group of pumps is: 7,957

The total number of pumps in this group is: 65

The average horsepower of pumps in this group is: 122

The average expected life of these pumps is (in years): 4.3

White Nile -- East Bank -- Kosti

02		1		?
02				?
16		2		?
37		10		?
64		2		?
28	14	5		1.1
53	16	2		3.7
26	20	5		2.0
04	22	5	400	3.1
04	22	5		3.1
06	22	2	200	4.5
26	22	2		2.0
28	22	2		1.1
57	22	5	100	2.4
57	22	5		2.4
06	24	2		4.5
38	24	5		4.9
61	24	1	70	3.0
62	24	2	85	1.2
62	24	5		1.2
62	24	5		1.2
31	25	2	150	6.2
46	25	5		1.4
28	26	5	68	1.1
46	26	5	68	1.4
53	26	7	150	3.7
59	26	7	400	3.0
30	30			?
33	30		150	5.2
44	30	2		3.9
47	30	2	200	6.9
58	30			3.6
64	34	2		?
14	34	2		2.0
30	34	1		?
52	34	7		2.2
54	34	7	490	4.5
55	34	5		4.3
07	35	5	860	5.3
13	35	5		3.9
21	35	2	300	3.7
22	35	5	300	4.0
25	35	5	300	4.0
26	36	5	150	2.0
29	36	10	400	3.4
29	36	10		3.4
52	36	2	150	2.2

03	37	2	200	5.6
51	37	2	200	5.6
59	37	2		3.0
69	37	5	300	8.4
09	40	2		3.3
19	40		330	2.9
34	40	5		2.2
36	40	5		4.2
38	40	5	300	4.9
56	40	5	348	3.8
10	42	5		5.6
14	42	5	150	2.0
15	42	5		6.9
25	42	2		4.0
32	42	2	250	6.2
45	42	2		4.6
22	43	5		4.0
05	44	5	350	3.9
12	46	2		4.3
18	49	2	200	4.2
21	49	2		3.7
29	49	15		3.4
44	49	2	300	3.9
45	49	5	400	4.6
49	49	2	200	4.2
50	49	5	500	10.6
16	50	2	550	?
05	50	5		3.9
24	50	5		4.1
27	50	5	300	6.2
40	50		300	6.2
41	50	2	400	3.3
42	50	2	200	4.2
43	50	2		3.0
48	50	5	375	7.8
07	55			5.3
23	55			3.1
39	55		400	3.5
56	55	2		3.8
60	55		264	2.2
37	58	5	550	?
36	58	5	400	4.2
10	65			5.6
39	65	5		3.5
15	67	5	720	6.9
20	67	5		3.5
43	67	2	340	3.0
58	67	10	2600	3.6
09	70	2		3.3
60	70	1		2.2
13	73	2		3.9

58	74	2		3.6
07	77	5		5.3
10	77	5	1000	5.6
19	77			2.9
23	77		400	3.1
24	77	5	500	4.1
41	77	2		3.3
59	77	2		3.0
54	80	7		4.5
58	80	7		3.6
20	81	2	500	3.5
01	88	5	750	4.4
01	88	5		4.4
04	90	2		3.1
13	90	5	750	3.9
34	90	5	270	2.2
55	90	5	515	4.3
58	90	5		3.6
67	95	5	1040	11.4
09	105	2	685	3.3
12	135	2	750	4.3
58	150	7		3.6
65	150		6102	13.7
63	156	2		?
63	156	5		?
65	156	2		13.7
65	156	2		13.7
66	156	2		1.1
68	156	5	1512	5.0
68	156	2		5.0
17	225	5	4130	9.5
17	225	5		9.5
58	225	5		3.6
63	300	5		?
08	360	5	400	0.6
08	360	5		0.6
11	360	5	4380	3.8
11	360	5		3.8
35	390	5	2040	1.8
35	390	5		1.8
35	390	5		1.8
11	480	5		3.8
66	767	5	1000	1.1

The total horsepower of this group of pumps is: 11,782

The total number of pumps in this group is: 141

The average horsepower of pumps in this group is: 84

The average expected life of these pumps is (in years): 4.1

TOTAL OF ALL PUMPS IN THESE THREE REGIONS

The total horsepower of this group of p s is:	42,790
The total number of this group pumps is:	283
The average horsepower of this group of pumps is:	151
The average expected life in years:	4.7

SUMMARY TABLE

RESULTS OF PARTIAL SURVEY OF SUDAN PUMPS

Grouped according to size and expected life remaining

(The number at the intersection of a column and row is the total of pumps sharing both a common size and remaining useful life)

REMAINING EXPECTED LIFE [years]

SIZE [horsepower]	1	2	3	4	5	6	7	8	9	10
14		1			1					
17										
20		3			5					
24	1	4			6		2			
29	1	5			1		2			
35		8			13					2
42	1	13			15		1			1
51		1			3					
61	1	2			15		2			2
73		5			6					
87		3			20		1			
105		1			1					
126	1	1			9		5			
151		7			9					
181		1			1					
217	1	2			5		2			
261	1				2		3			
313	1				7		15			
376					5		3			
451					2		4			
540							1			
650					1		4			
780										
940							1			
1120							1			
1350										
1620										
1940										
2330							1			
2800										

SUMMARY TABLE

RESULTS OF PARTIAL SURVEY OF SUDAN PUMPS

Grouped according to size and expected life remaining

(Each dot represents one pump, i.e. the number of dots at the intersection of a column and row is the total of pumps sharing both a common size and remaining useful life)

SIZE [horsepower]	ESTIMATED REMAINING LIFE [years] 1	2	3	4	5	6	7	8	9	10
14										
17										
20		•••			•••••					
24	•	••••			••••		••			
29	•	•••••			•		••			
35		••••			••••					••
42	•	••••			••••		•			•
51		•			•••					
61	•	••			••••		••			••
73		•••••			••••					
87		•••			••••		•			
105		•			••••					
126	•	•			••••		•••••			
151		••••			••••					
181		•			•					
217	•	••			•••••		••			
261	•				••		•••			
313	•				••••		••••			
376					•••••		•••			
451					••		••••			
540							•			
650					•		••••			
780										
940							•			
1120							•			
1350										
1620										
1940										
2330							•			
2800										

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