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WOOD GASIFICATION AS AN APPROACH FOR REDUCING OIL IMPORTS IN LIBERIA

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Like many other developing countries, the West African country of Liberia faces serious economic problems stemming from its dependence on oil imports. Clearly, substituting domestic energy resources for imported oil would aid the country's balance of payments situation, inject money into the domestic economy, and in many other ways benefit national social and economic development.

This paper describes an option which appears promising for this purpose and may be of interest to other oil-dependent countries with a substantial potential for biomass production.[1] Information assembled as part of a recent national energy assessment in Liberia indicates that the country's abundant wood resource base, combined with available wood gasification technologies, could meet a variety of energy needs now being met with imported oil.[2] If several institutional issues can be resolved satisfactorily, it seems that such an option will be highly attractive economically, at least when it displaces diesel fuel rather than less expensive residual fuel oil.

The following sections of the paper briefly review Liberia's present energy picture, describe the nation's wood energy resource, characterize and compare available technologies for using wood, present preliminary analyses of three hypothetical applications of the most promising approach, and note potential difficulties and possible resolutions of them.

ENERGY AND THE LIBERIAN ECONOMY

Liberia is a small developing country on the west coast of Africa, with a total land area of about 43,000 square miles. About fifteen percent of its two million people live in the urbanized area of Monrovia, the capital city; some parts of the interior are quite sparsely populated. In 1981, the Gross Domestic Product of the country (GDP) was $841 million for the monetary economy and about $1 billion for the monetary and traditional economies combined (roughly $500 per capita).[3]

From the period of World War II through most of the 1970's, the economy of Liberia was strong, based largely on exports of iron ore, rubber, and wood produced by foreign concessions. More recently, however, the country has been mired in a severe recession. In 1980, real GDP in the monetary economy fell by five percent; in 1981, it fell by another five percent.[4] Preliminary information indicates that this trend continued in 1982 and early 1983 without any significant signs of economic recovery. Growing government deficits led to reductions in government salaries by 17 to 25 percent in 1983.

The major reason for this situation appears to have been a reversal in Liberia's import-export balance. During the 1970's, import bills grew steadily, and the longstanding favorable trade balance disappeared by 1977. Since then, annual imports have exceeded exports. Moreover, in 1981 Liberian exports dropped substantially because of weaknesses in international markets and increased competition from other countries.

Liberia's energy picture is closely tied to these difficulties. The country consumes about three million barrels of petroleum products

annually, all refined from imported oil or imported as refined products. Between 1978 and 1980, the cost of oil imports rose from $85 million to $152 million, a 79 percent increase in two years. With the recession, the bill for oil imports fell to $130 million in 1981, about 24 percent of all imports; but this still represented a sizeable increase from a level of $5.5 million ten years earlier, when oil purchases accounted for only 7 percent of the cost of all imports.[5] This trend had a substantial impact on the nation's ability to invest in infrastructure improvements and other economic development activities, and it contributed to a growing burden of indebtedness.

ENERGY SUPPLY AND USE IN LIBERIA

The predominant use of imported oil in Liberia is to fuel stationary internal combustion engines, mainly for the generation of electricity. About 60 percent of Liberia's oil is consumed in the operation of iron ore mines, largely to provide electricity; about 30 percent for transportation; and about 6 percent to generate electricity for the Monrovia area and nine small urban areas elsewhere in the country. The remainder is used primarily in agriculture, forestry, and for lighting in residential buildings, especially in rural areas. Roughly half of all the oil products consumed in the country are used to produce electricity.[6]

Despite the substantial use of imported oil, domestic resources have always met most of Liberia's energy needs. For example, fuelwood and charcoal supply most of the country's energy for cooking. Preliminary estimates indicate that Liberians annually consume about 3 million tonnes of wood, along with another 100,000 tonnes of charcoal.[7] In addition,

hydroelectric power supplies 70 percent of the electricity for the regional grid centered on the capital city of Monrovia, and the Firestone rubber plantation in Liberia relies on a hydroelectric facility to meet most of its power requirements. These hydroelectric facilities save the nation the equivalent of about 540,000 barrels of imported oil each year. Together, wood and hydroelectric energy now provide about two-thirds of the energy consumed in Liberia.

Speculation about further uses of domestic resources to meet Liberia's energy needs, especially as the economy develops in the future, has revolved around three possibilities: domestic oil production, further development of hydroelectric potentials, and deriving further energy from biomass (primarily wood) to meet the needs of Liberia's modern sector. Because of prevailing environmental and economic conditions, other resources -- such as solar energy, wind, and alcohol fuel from crops -- are less promising as major contributors to the nation's energy situation.

Exploration for oil in Liberia's continental shelf and slope is scheduled to resume in late 1983 or early 1984, and there is some reason to believe that a modest level of production will eventually be possible.[8] At this time, however, the potential for domestically-produced petroleum remains speculative (although the prospect of oil development sometimes tends to divert attention from other energy options that may be better bets). The National Energy Committee, an interagency coordinating body within the Government of Liberia, has urged that if oil is discovered a substantial part of the royalties be invested in developing

domestic renewable energy resources. If domestic oil reserves are not discovered, of course, such other sources will be even more important.

As noted above, both of the two major renewable resources, hydroelectric potential and woody biomass, are already a part of Liberia's energy picture. The central question is whether their roles can be increased significantly. With considerable local relief within 100 miles of the coast and with an annual rainfall of up to 200 inches, Liberia has considerable hydroelectric potential, but it faces two problems in developing it. First, the rainfall is highly seasonal. For example, at the nation's largest existing hydroelectric facility (the Mt. Coffee plant, supplying the Monrovia area), the 64 megawatt (MW) generating capacity during the height of the rainy season utilizes only a part of the river flow. During the dry season, however, capacity falls as low as 10 MW, with virtually all of the river flow utilized. This seasonality means either that backup thermal generation capabilities must be provided or that large storage reservoirs must be created. Either solution adds significantly to the cost of hydroelectric power.

In Liberia, two large-scale storage systems are presently under consideration. Either could easily meet the projected electricity needs of the Monrovia area and a part of the iron ore mining industry; but neither is likely to be implemented very quickly, even if financing can be found, and neither will contribute very much to meeting rural electric or non-electric energy needs.[9] Other options include smaller hydroelectric facilities and smaller increments of large facilities; but smaller facilities are affected even more seriously by seasonal variations in river flow, and attractive sites near demand centers are

limited. In the long run, it seems clear that hydroelectric power will play an important role in Liberia, but in the near term its prospects are limited by the fact that it requires substantial front-end capital investments relative to the amount of power supplied.

Even excluding the "virgin" rainforest, Liberia has an impressive wood resource base. The energy value of annual stemwood production in the country has been estimated at 100 to 200 million barrels of crude oil equivalent, as compared with annual oil imports of about 3 million barrels.[10] Roughly 20 percent of the land area is in "high forest," and more than half of the remainder is in secondary growth and agriculture.[11] Unlike many other developing countries, Liberia is not facing a fuelwood shortage; the current gathering of wood for fuel and charcoal production uses only a small part of the resources available from secondary growth forests, retired rubber trees, and forest industry wastes. Preservation of the rainforest continues to be a major problem, but fuelwood needs are not a significant cause of this problem.

In general terms, wood is attractive as an energy resource for three reasons. First, it is well-suited to decentralized development, because capital and skill requirements for entering the supply system are relatively low. For instance, an effective private-sector system of small charcoal producers and transporters already provides the Monrovia area with reasonably priced charcoal and fuelwood. Second, ample resources are usually available in close proximity to each demand center, large or small, reducing the requirements for transportation. And, third, a relatively large part of the cost of wood energy is local wages, in contrast to such options as hydroelectric energy, where most of the

cost is for capital facilities (with payments going abroad rather than staying within the local economy).

ALTERNATIVES FOR ENERGY PRODUCTION FROM WOOD IN LIBERIA

Given the rate of biomass growth in Liberia and the abundance of the wood resource, it makes sense to take an especially hard look at this option for reducing oil imports. For example, consider a 600 kilowatt (kW) electric power generator, supplying electricity to a small urban center, now fueled by diesel oil. A sustainable wood supply for a generator of this size would require about 200 acres of untended land on a five- to seven-year rotation--assuming a 13,000 Btu/hour heat rate, an average load factor of 40 percent, 17 million Btu per dry ton of wood, and about 50 dry tons of wood per acre after six years of growth. In a rural area, a wood energy supply system might even be integrated with the common practice of shifting agriculture, with wood harvested at the end of the fallow period instead of being burned in place and ash from energy production returned to the plot to replace at least part of the fertilizer lost by burning the wood off-site.

To meet a major part of Liberia's energy needs in the modern sector, wood can be converted into energy in three ways: (1) direct burning to provide process heat or generate steam-electric power, (2) liquefaction to alcohol (methanol or ethanol), or (3) gasification. The direct

burning of wood to produce steam for either electric power generation or industrial use is a familiar alternative, based on established technologies. Two wood-powered steam systems are now operating in Liberia: a 500 kW cogeneration unit providing electricity and steam for a sawmill and plywood operation at a rural location and a process steam unit at the Firestone Rubber plantation consuming about 500 pounds of wood per hour. Although steam facilities appear attractive in a number of situations, their potential in the near term is limited by the requirement for skilled operating personnel and by economies of scale. Steam-electric systems, for instance, are generally only economically attractive in the Liberian context in sizes of a few thousands kilowatts (roughly a few tons of wood per hour) or greater; and only a few demand centers in the country require this much electricity.

The conversion of wood (cellulose) into alcohol is another option which is technically feasible, and it deserves further study as a long-term option for meeting liquid fuel needs in Liberia. In the near future, however, the infrastructure requirements for such a sophisticated approach to wood conversion are beyond Liberia's capabilities, and the available conversion processes are too expensive to compete with petroleum-based fuels (3-4 times the cost of residual fuel oil).[12]

Wood gasifiers are a third method for utilizing the energy potential of wood. In this approach, a "producer gas" (mostly carbon monoxide and hydrogen) is produced through the partial combustion and thermal decomposition of wood. This gas, with an energy content 10 to 20 percent that of natural gas, is then ignited in a spark-ignition or diesel engine attached to the gasifier. In a spark ignition engine, the gas totally

replaces the liquid gasoline fuel, but engine power is reduced by the low energy value of the gas. Alternatively, a different fuel mode may be adopted, with gasoline used automatically at startup and to meet peak power requirements. For a compression ignition engine, dual fuel operation is required; some diesel fuel (10 to 30 percent of normal) must be injected for ignition.

Wood gasifiers are known to be technically and economically viable over a wide range of scales, applications, and levels of technological complexity, from simple units designed to power a small motor vehicle to sophisticated units large enough to fuel a several megawatt electricity generator. For instance, very small gasifier units of 10-15 horsepower each are in operation in the Philippines, supplying power for fishing boats.[13] The largest wood gasifier currently in use operates at a scale of 70-80 million Btu/hour, equivalent to 5-7 MW or 7-9,000 horsepower.[14]

During World War II, petroleum shortages led a number of European countries to use wood and coal gasifiers to fuel trains, buses, trucks, and automobiles. More recently, as part of a more comprehensive "dendrothermal" energy program, the Philippines has undertaken a major wood gasification program; and 5000 gasifiers are now in use, mainly for irrigation pumps, motor vehicles, and boats. Brazil has also promoted the use of gasifiers.[15]

Although steam power generation is also feasible in Liberia, we believe that two characteristics of wood gasification make it a more attractive candidate for widespread use in the country. One advantage is its potential to meet energy needs at a wide variety of scales and a wide range of technical skill requirements. The other is its potential to

utilize the existing stationary internal combustion engines, which embody a substantial capital investment that has already been committed, while at the same time reducing oil consumption by these engines.

WOOD GASIFICATION IN LIBERIA

There is little potential for wood to displace oil products in Liberia's transportation sector in the near term. Such fuels as gasoline and diesel fuel will continue to be needed, especially for road transportation. In the longer term, gasifiers and alcohol fuels have the potential to displace some (or even most) of these petroleum fuels, but the technological and economic challenges are considerable.

The utility and industrial sectors, however, are a different matter. As noted above, more oil products are consumed each year for electricity generation than for transportation in Liberia. In addition, oil products are used to operate sawmills, boilers, and other stationary equipment. Together, these sectors consume about 2 million barrels of oil each year, equivalent to nearly two-thirds of the nation's oil imports; and consumption may rise in the years ahead.[16] For many purposes, wood can be used as a substitute source of energy, and gasification makes it possible to utilize generators and other equipment already in place.

Consider, for instance, the costs and benefits associated with very large displacement of imported oil by wood gasification. We estimate that replacing half of the oil products now consumed for electricity generation in Liberia, or about 700,000 barrels of crude oil equivalent each year, would require a capital investment in the range of $50-75

million ($45 million if the plant load factor is 70 percent, $75 million if it is 40 percent). This level of capital expenditures compares with fuel cost savings of about $30 million a year (the total price of crude oil delivered to Monrovia in 1982 was above $40 per barrel). And it can also be compared with the $69.1 million in grants and loans from the United States to Liberia in 1981.

Clearly, one would not embark on such a massive program without testing the technologies and examining the implementation strategies carefully. But a multiple program to exploit the energy potential of biomass in Liberia, with each phase dependent on the success of the previous one, could become an important part of turning the economic situation in Liberia around.

As a first step, we conducted engineering-economic analyses of three hypothetical wood gasification facilities in Liberia: (1) a unit replacing diesel fuel consumed in sawmill operations, (2) a unit replacing diesel fuel in a small electricity generation facility in a rural area, and (3) a unit replacing fuel oil in a large electricity generation facility. Tables 1, 2, and 3 present the results of these analyses. The estimates are conservative in that they are generally based on relatively pessimistic interpretations of the best data currently available; in several instances (such as maintenance costs and operator wages), cost estimates were raised well above best estimates of prevailing conditions. Even so, the cost estimates must be considered provisional until wood gasifiers are actually demonstrated in Liberia.

The results of the analyses are encouraging, at least where wood gasification is displacing more expensive diesel oil rather than less

TABLE 1. WOOD GASIFICATION FOR SAWMILL OPERATIONS

The System. Two simple Philippine-type gasifiers supplying energy for a 175 horsepower engine, displacing diesel fuel

Costs:

Capital cost:	
The gasifiers (assume triple the Philippine cost of $3000/80 hp or $112.5/hp)	$20,000
Storage shed, chipper, and dryer (hopper to recycle exhaust to dry wood	15,000
Total	$35,000
Operating costs	
Maintenance at 5% of capital costs	1,750/yr
Operations: 1 employee at $250/mo.*	3,000/yr
Wood purchases: sawmill wood scraps and trimmings available at no cost	0/yr
Total	$4,750/yr

Benefits

Value of diesel fuel displaced at non-concessionary market price is $2.40/gal.; 14,000 gal./yr x .85** x 2.40 = $28,560	$28,560/yr
Total Net Benefits $	23,810/yr
Undiscounted Payback Period: capital costs of gasifier divided by annual savings	1.47 years
Oil Products Displaced, in barrels of diesel fuel	283/yr
Capital Cost per Barrel Displaced: first year	$ 124

*About 65 percent above prevailing wage rates.

**Assuming 15% of energy requirements provided by diesel fuel.

TABLE 2. WOOD GASIFICATION FOR RURAL ELECTRIFICATION

The System. Electricity generation assuming a peak load of 250 kW, 24 hour operation, average load factor of 50%.

Costs:

Capital costs:	
The gasifier: assuming three 125 kW engines for reliability, heat rate of 13,000 Btu/kWh; 375 kW equivalent to 502.5 hp; cost at $112.5/hp (see Appendix A)	$57,000
Sheds, chipper, dryer	40,000
Total	97,000
Operating costs:	
Maintenance at 5% of capital costs	4,850/yr
Operations: 4 employees at $250/mo.*	12,000/yr
Wood purchases: requirement of 16,100 million Btu/yr: 250 kW x .5 x 13,000 Btu/kWhr x 8760 hr x (.85 divided by .75)** --at $2/million Btu delivered wood	32,200/yr
Total	$49,050

Benefits:

Value of diesel oil displaced: refinery price is $1.04/gal.; conservatively assume price of $1.20/gal. delivered;*** diesel fuel displaced is .85 x (1.4235 x 10^{10} divided by 138,700) x 1.20 = 104,680	$104,680/yr
Total Net Benefits:	55,630/yr
Undiscounted Payback Period:	1.75 yr
Oil Products Displaced: in barrels of diesel fuel	2,077/yr
Capital Cost per Barrel Displaced: first year	$ 46.70

*About 65 percent above prevailing wage rates.

**Assumes 15% of energy requirements provided by diesel fuel.

***Liberia maintains a 2-tier pricing system for diesel fuel. Certain large buyers, including the Liberian Electricity Corporation, pay a price equivalent to importing the refined product, while other buyers pay a substantially higher price.

TABLE 3. WOOD GASIFICATION FOR LARGE-SCALE ELECTRICITY GENERATION

The System. A 10 million Btu/hour gasification unit based on U.S. technology, supplying a part of the energy for a relatively large engine: e.g., about 1 MW of the capacity of a Liberian Electricity Corporation unit at the Monrovia Generation Plant, displacing fuel oil. Since the gasifiers supply only a small part of the plant's requirements, they are assumed to operate at a 70% capacity factor.

Costs:

Capital costs:	
The gasifier: base cost of $200,000; installed cost in U.S. of $400,000; assume $600,000 for Liberia--includes ancillary equipment	$600,000
Operating costs:	
Maintenance at 5% of capital costs	30,000/yr
Operations: 4 employees at $250/mo	12,000/yr
Wood purchases: $2.00 per million Btu delivered wood, at a gasifier efficiency of 75% and a 70% capacity factor	163,520/yr
Total	$205,520/yr

Benefits:

Value of oil displaced, assuming fuel oil cost of 76¢/gal. or $5.07 per million Btu	$310,890/yr
Total Net Benefits: $310,890 - $205,520	105,370/yr
Undiscounted Payback Period: $600,000/105,370	5.7 years
Oil Products Displaced: in barrels of fuel oil	9740 bbls/yr
Capital Cost per Barrel Displaced: first year	$61.60

NOTE: The use of larger gasifier units or multiple units would reduce this payback period. Also, this analysis is based on the current price of petroleum. If petroleum prices should increase at a faster rate than wood costs or general inflation, the payback period would be reduced.

expensive residual fuel oil. In the sawmill case (Table 1), in which the wood is free (i.e., wood wastes are a byproduct of normal operations), the operator recovers most of the front-end capital investment in the first year; by the second year, the investment has become highly profitable, and the profit continues throughout the life of the equipment (conservatively estimated at 5 years under Liberian conditions). In the rural electricity generation application, where the wood must be purchased, the payback period is still less than two years, even assuming that the price of delivered wood is $2 per million Btu's of energy content, which we believe is toward the upper end of the likely range of wood costs (preliminary analyses of wood production, harvesting, and transport in Liberia indicate that actual costs would be between $1 and $2 per million Btu's). The larger scale application is less attractive because it assumes a far more expensive type of gasifier and because it displaces less costly residual fuel oil; but it still appears to be worth considering if estimates of other potential benefits are added, such as the value for the national economy of making energy purchases domestically.

This latter point is especially important. When wood is purchased in Liberia, circulating money within the national economy, as contrasted with oil purchases which drain money out of the national economy, a stimulus for income growth and development results. Assuming a multiplier of two (some would estimate it as high as four or five), every dollar now spent for imported oil that is spent instead for Liberian wood will mean a two-dollar contribution to the Liberian economy. In the example above, in which 700,000 barrels of crude oil are displaced by

wood gasification, a yearly outflow of more than $30 million would be replaced by domestic purchases amounting to more than $10 million, with a total value to the national/regional economy of more than $20 million each year (in addition to annual savings in energy costs and benefits in the national balance of payments).

The major issues which need to be resolved before making a major commitment to wood gasification in Liberia appear to be: (1) the infrastructure requirements for a reliable and sustainable wood supply and (2) the maintenance requirements for the gasification systems. Although the wood resource is indeed abundant, gasifier operation requires that the wood supply be steady, regardless of weather or personal vicissitudes. For example, the rural electrification case analyzed in Table 2 calls for a daily supply of about 45 million Btu's per day of wood (about 28 tons per week). Except for such cases as a sawmill, where wood supply is assured internally, most gasifier operators will want to arrange for wood supply by contract with someone else; and it is not entirely clear at this point what their options will be.

Recently, for example, the Bong Mining Company (operator of Liberia's second largest iron ore mine) indicated an interest in using wood for process heat, in place of residual oil. If they were to convert to wood as an energy source, at least for the application they have in mind, they would need about 100 tons of wood per day. This, in turn, would require the harvesting of 2 to 3 acres per day, sustained for a number of years, and the delivery of wood to the mine in all seasons. In response to a request for proposals to supply this quantity of wood, a number of Liberian entrepreneurs came forward with proposals; but in

every case the proposed activity would represent a venture in a new field, and in most cases the new enterprise would be substantially larger than the bidder's current business operations. Clearly, the risk is considerable that the supplier would encounter unforeseen difficulties. As of mid-1983, the Company had not yet signed a contract with a wood supplier, although it continued to show an interest in this option.

In addition, if wood gasification is to become a major factor in the Liberian energy picture, wood production will need to be transformed from a gathering-type activity to a sustainable cultivation-type activity, at least in the vicinity of most demand centers. Such countries as the Philippines offer a model of possible institutional structures for the future, but in Liberia the way has not yet been paved to get from here to there.

Maintenance and operational requirements are also an issue. Gasifiers need careful maintenance. For instance, filters and cooling systems must be cleaned periodically, and the system must be checked for gas leaks. During operation, an operator must be able to adjust air, gas, and fuel flows to keep the system running smoothly. Experience in the Philippines and Brazil has shown that mechanical aptitude and skills in those countries are sufficient for gasifiers to be used effectively,[17] and such aptitudes appear to be present in Liberia. But it is clear that mechanical equipment in Liberia is often poorly maintained, although the reasons are complex. Most likely, implementation of wood gasification in Liberia would require deliberate steps to assure that spare parts are readily available and that operators are well trained and highly motivated.

CONCLUSION

Based on information developed by a comprehensive energy assessment, we conclude that Liberia can reduce its oil imports by substituting domestic energy resources for a number of purposes. Wood is an especially attractive option: abundantly available, capable of being developed rapidly with relatively simple and inexpensive technologies, and a possible source of jobs and income for a large number of Liberians. Because of its potential to be applied at a variety of scales and levels of technological complexity, and because it can be retrofitted to internal combustion engines currently in use, we believe that wood gasification is the most promising approach for utilizing wood to meet the nation's energy needs. If more detailed feasibility studies support this conclusion, the gasification option should be demonstrated. If several demonstrations are successful (and if capital resources are available on reasonable terms), normal economic incentives should then be sufficient to assure implementation more widely in the Liberian economy. Such a sequence could have a noticeable impact on oil consumption before the end of the decade, and in the longer term it has the potential to supplant a major share of Liberia's current oil use.

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