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A RESEARCH STRATEGY TO PERMIT GREATER UTILIZATION OF DOMESTIC FOSSIL ENERGY RESOURCES

March 1983

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Energy Technology Programs
Department of Energy and Environment

DEPARTMENT OF ENERGY AND ENVIRONMENT

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CARBON MONOXIDE - RESOURCE OF THE FUTURE - CATALYSIS

Abstract

The economic strength and security of the nation would be well served by having available a clean multipurpose feedstock for use as a source of future industrial raw materials and fuels. Carbon monoxide and synthesis gas (mixtures of carbon monoxide and hydrogen) qualify as such key materials. Easily produced on a commercial scale from many different sources of carbon, carbon monoxide can be the basic building block for fuels and chemicals production. The development and improvement of synthesis methods based on this future feedstock are necessary to realize its full potential as a common resource within a reasonable time frame.

Introduction

Although the need for kerosene for illumination purposes provided the first motivation for the development of the petroleum industry, it soon became evident that petroleum would provide an almost unlimited source of raw materials for the production of many and varied products. The development of the internal combustion engine changed the product emphasis from illuminants to fuels while commercial and military needs drastically changed the requirements for fuels and introduced demands for new products such as synthetic rubber, solvents, coatings, and explosives. The petroleum industry had to adjust to the changed requirements. Every variation in supply or utilization has a multiple impact, but it took an oil crisis before the general public became aware of this relationship and its importance to the world economy.

But what about the future? U.S. Department of Interior Geological Surveys estimate we have a forseeable depletion (30-40 years) of recoverable resources of conventionally producible oil with a potentially longer lasting supply of natural gas. We have abundant reserves of coal and shale oil, but lack economical technologies to have these substitute directly for petroleum in the immediate (30-40 years) future. This depletion concept, however, completely ignores the substitution of alternative resources. Thus, there may never be a time when we pump the last drop of oil.

Needed are short and medium range approaches which emphasize increasing the availability and flexibility of raw materials for the chemical and energy industries within the context of available resources. Long-term goals should focus on replacing fossil raw materials in the energy sector with regenerable sources to extend their availability to the chemical industry.

A step by step replacement of oil by other resources is necessary. Increasing price and scarcity will compel this substitution strategy. This change is possible if direct coal utilization for power and heat production is increased, if there is further development of process technology to accommodate more varied feedstocks for petroleum products, and if a versatile, multi-sourced, long-term feedstock such as carbon monoxide is available to augment these alternatives.

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The future of carbon monoxide as this key material seems to be assured since it can be produced on a commercial scale from virtually any source of carbon. It has been manufactured by both steam reforming and partial oxidation of natural gas, naphtha, heavy fuel oil and coal. In fact, it can be obtained by similar treatment of almost any organic material including agricultural and forestry wastes, tar sands, oil shales, and even garbage. It should also be noted that proponents suggest that the initial application of nuclear process heat in the chemical industry be used for the production of synthesis gas.

The revival of carbon monoxide chemistry will pave the way to the synthesis of fuels and chemicals. Commercially important today for the production of carboxylic acids, ketones, formamides, and ureas, carbon monoxide can be converted to virtually any organic commodity from methane to margarine. Thus, the resource of the future is, in reality, carbon monoxide. The generation and utilization of this key reactant forms the basis for ongoing and future research.

Future Aspects of Energy and Raw Material Supply

Product and resource substitution has been the lifeblood of the chemical industry. This is an evolutionary process with long lead times so it is necessary to begin planning before an urgent need exists. One should not expect massive breakthroughs in technology such as those attributed to the space effort. This means continued dependence on the petroleum processing infrastructure.

A priori, natural gas is the most economically attractive alternative to crude oil. There is more gas available worldwide at reasonable prices than there is oil. In a comprehensive two-year assessment, the American Gas Association Supply Committee concluded that sufficient conventional natural gas will be available in the year 2000 to supply 25-35% of the nation's total need for energy. These estimates do not include the so-called non-conventional sources such as tight-gas formations, Devonian shales, coal seams, geopressured aquifers, and gas hydrates which cannot be estimated. These resources are not recoverable under current economic conditions, but advanced technology and future energy prices may permit their eventual exploitation, with the potential of doubling current estimates of remaining recoverable resources.

Currently, 95% of natural gas is used as a fuel, but with conservation measures such as improved residential insulation and the greater use of coal for utilities and for industrial heating, a shift in natural gas usage is likely. The direct chemical utilization of methane, the major component of natural gas, is limited by its chemical stability and molecular simplicity. The best approach for the large-scale chemical utilization of natural gas is through synthesis gas. This conversion process is inexpensive, efficient, and based on well-known technology. Although the substitution using synthesis gas chemistry is based on known technology, innovative R&D will be needed to provide products with an economic substitutive advantage.

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Focusing on the medium-term, the substitution of other energy sources for oil and natural gas is the most prudent solution if we are to avoid competition for resources by energy and feedstock users. Petroleum will become solely a chemical feedstock but the overall infrastructure could remain virtually unchanged if coal based technology can successfully substitute in certain areas. Economies of scale dictate a coal program be centered around a single but versatile, multipurpose raw material. Coal gasification to yield synthesis gas or carbon monoxide is the most promising and environmentally acceptable approach and would sequentially and economically replace some of the natural gas generated feedstock. Other coal-based contributions such as the terephthalic acid process, carbide and acetylene production or direct coal liquefaction will be minor. The large scale of operation needed for acceptable economics is difficult to visualize for these processes.

The long-term situation will demand widespread utilization of the so-called infinite energies: solar, geothermal, nuclear fusion or nuclear breeder reactors. (The free world supply of fissionable uranium is inadequate for nuclear fission to qualify as a major or long-term energy source.) At the same time however, energy storage and transportation problems must be solved.

Gas and oil, will only be employed as raw materials. Coal will supplement the production of energy (particularly electric) by infinite sources and more importantly, serve with oil and gas as a raw material. Nuclear might combine with coal for the manufacture of synthesis gas via coal gasification and serve in the manufacture of hydrogen from water which could result in a wider use of hydrogen as an energy source and in the replacement of hydrogen manufactured from fossil materials.

Although not mentioned in this scenario, any substitution strategies using biomass, shale oil, and oil sand technologies, other than direct combustion, are functionally dependent on synthesis gas technologies as well.

This perspective of future energy supply depends heavily on the development of new and improved technologies based upon synthesis gas and carbon monoxide - the true resource base of the future.

The New "Mixed" Petrochemical Economy

Fuels are the most important products of petroleum refineries but the manufacture and use of chemicals has a major impact on the economy of the country. Although a small percentage of the total oil consumed now, various studies have indicated the projected U.S. demand for petrochemicals will grow enormously. How can carbon monoxide chemistry help provide the needed change in refinery patterns?

Transportation Fuels

It is possible to design refineries specifically to convert a barrel of oil only into chemicals making no fuels whatsoever. With this, how can our country's large transportation fuel appetite (amounting to 25% of all energy consumption goes for transportation) be met? The answer lies in the pro-

duction of synthetic fuels by the catalytic reactions of carbon monoxide. The major limitation of this chemistry is usually the degree of selectivity with which desired fuel composition ranges can be met although this restriction is not very severe since fuels have reasonably broad composition ranges.

Over the last five years, the greatest impact on the synthesis of fuels has been the development by Mobil of a gasoline synthesis process. In a two step process, synthesis gas is first converted to methanol and the methanol is selectively converted, over a strongly acidic shape-selective zeolite cage catalyst, directly into a high octane gasoline. Thus, this process alone may radically alter refinery patterns away from converting petroleum into gasoline, the largest end use. The process has the advantages of simple operation, mild reaction conditions, and high efficiency with a minimal environmental impact. The product is of high quality containing neither sulfur nor nitrogen while having few byproducts and requiring no special refinery treatment.

Although a near-commercial development, the methanol to gasoline process has some limitations and future research in this area should be pursued. If analagous upgrading technologies could be developed for other initial synthesis products, including the direct reaction of carbon monoxide, the possibilities for economical couplings of synthesis conditions, catalysts and products are greatly increased. Improvements in the methanol synthesis (to be discussed later) would also have great impact in this area.

One limitation of the shape-selective processes is that straight-chain hydrocarbons, the major components of diesel and jet fuels, cannot be produced. In the event of a national emergency, there would be a tremendous demand for jet fuels. This requirement could potentially be met using the Fischer-Tropsch synthesis, a process used by Germany during World War II to supplement her small supplies of crude oil which consists of hydrogenating carbon monoxide in the presence of a suitable catalyst. The broad product distribution and low activity of the catalysts are the major limitations of this chemistry.

Since the Fischer-Tropsch reaction generates straight-chain hydrocarbons, fractions of the products in the diesel boiling range usually possess exceptionally high cetane numbers. (The ignition properties of diesel fuels are expressed in terms of cetane number, analogous to the octane number ratings for gasoline.) The straight-chain structure is also important in jet fuels. The low sulfur and nitrogen content of the product combined with this structural feature makes possible environmentally higher quality fuels than are currently available. For example, less sooting would be an added benefit of a Fischer-Tropsch derived diesel fuel. A variation of this type of reaction using carbon monoxide and water instead of carbon monoxide and hydrogen, the Kolbel-Engelhardt synthesis, is also possible. Much research needs to be done in these areas with regard to the development of improved catalysts.

Finally, the concept of large-scale production of fuel-grade methanol should be considered. Interest in methanol has been high because of methanol's clean burning qualities, but its low energy content and problems

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with fuel distribution will delay acceptance of methanol transportation fuels. Instead, methanol could serve as a ready replacement for petroleum fuels used in power generation and, more importantly, as a chemical feedstock.

Chemicals

Fuels have been the most important products of petroleum refineries, but the increasing demand for petrochemicals will accentuate the value of petroleum as a feedstock. In the U.S., chemicals and related products account for about 6% of the total energy consumption.

Over 250 billion pounds of chemicals per year come from petroleum and natural gas. That is almost 1200 pounds of chemicals per year for every man, woman, and child in the U.S. Variation of the raw material supply for these chemicals or a large change in product demand would reflect seriously throughout the economy. In general, the future petrochemical infrastructure could remain virtually unchanged if carbon monoxide and synthesis gas products are introduced into the market place.

Synthesis gas is an already important feedstock for the production of major chemical intermediates. Some of the leading volume chemicals such as ammonia and methanol are currently manufactured from synthesis gas. These two chemicals alone could be future chemical intermediates.

Ammonia, on which our fertilizer industry centers, is the largest volume chemical derived from petroleum. Industrial applications of ammonia are growing slowly but its ties to the polymer and plastics industries are enormous. Synthesis gas provides the hydrogen for ammonia synthesis via the water-gas shift reaction. Improvements in catalysts for this reaction are needed. Present systems have the disadvantage of operating at high temperatures where the equilibrium is not favorable. A catalyst which could operate efficiently at low temperatures and under low carbon monoxide pressure would represent a substantial advance, alleviating multiple pass operation and the need for incorporating carbon dioxide adsorption in order to force the equilibrium. It should be noted that carbon monoxide derived hydrogen is needed for the important hydrocracking and hydrotreating refinery steps and future oil shale usage.

In the long term, methanol represents the most promising commodity chemical. The synthesis of methanol from carbon monoxide is a large scale and commercially proven process. Technology development and marketing efforts for current and developing chemical syntheses based on methanol indicate its dramatic growth and potential as a feedstock. It is a key chemical in the synthesis of esters, formaldehyde, acetic acid, MTBE (octane additive), and higher alcohols. Future processes for the production of light olefins, glycols, vinyl acetate, chloromethanes, and polymers represent exciting new developments. The Mobil methanol-to-gasoline process and related reactions demonstrate more specifically the enormous potential of this intermediate. Even single cell proteins (SCP) can be derived via methanol. Methanol can also be viewed as an easily transportable energy intensive substitute for synthesis gas, allowing commodity trading and facile storage.

New methanol catalyst developments could result in a more economical process by minimizing the operating pressures and increasing throughputs. This possibility is especially significant if the acceptable product spectrum is expanded to include higher alcohols and other compounds which could be used in the Mobil process.

The Fischer-Tropsch and Kolbel-Engelhardt syntheses deserve additional mention. These reactions can be adapted for the production of a wide variety of chemical products in the future including, perhaps, ethylene, propylene, and naphtha. Although the ordinary synthesis centers on its ability to produce diesel and jet fuels, techniques have been and are being evolved which make possible the production of polymers, lubricants, waxes, fatty acids, edible fats, soaps, synthetic detergents, and other miscellaneous chemicals of almost any chain length, degree of unsaturation and structure depending upon the choice of reaction condition and catalyst employed. This flexibility provided Germany with a degree of self-sufficiency from imported petroleum sufficient to foster her economic and social development and to eventually allow her to wage World War II.

Much catalyst research and development work in this area is needed with particular emphasis on high alcohols, alpha-olefins, and polyethylene manufacture. These chemicals alone form a major part of the petrochemical industry.

There are many other recently recognized routes to chemicals from carbon monoxide and synthesis gas which go beyond the scope of this report. In general, these represent only the "tip of the iceberg" and extensive research should continue to generate new downstream processes which could greatly affect the future petrochemical industry. As an example, the synthesis of polyethylene involves 8% of U.S. oil consumption, but the direct synthesis of this important polymer can be accomplished using carbon monoxide and hydrogen. This approach, using the original noble-metal catalysts, could not compete with current ethylene based processes, but new, lower cost catalysts could make the synthesis gas route an important process.

Finally, synthesis gas and carbon monoxide can become a substitute building block, with petroleum-derived reagents replacing chemicals for other needs. For example, acetonitrile might be derived from synthesis gas and ammonia, terephthalic acid from toluene and carbon monoxide, and higher alcohols and higher amines from Fischer-Tropsch reactions modified with methanol or ammonia.

These future trends and examples illustrate the change of feedstocks which will occur in the chemical industry. Just as coal derived acetylene, an important feedstock from 1910-1950, was replaced due to cheaper, more readily accessible and workable petroleum-derived olefins and dienes, these, in turn, will be and are being replaced by multi-sourced synthesis gas and carbon monoxide.

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Conclusions

The extent to which the petroleum industry will be able to follow along the lines of present technology depends profoundly on the extent to which synthesis gas and carbon monoxide processes can succeed. Incentives for research lie in cost increases, supply reductions and disruption of conventional raw materials.

Although a research area currently receiving major attention from academic, industrial, and government laboratories, efficient catalysts for the activation of carbon monoxide need to be designed and their fundamental reaction mechanisms understood. This chemistry is presently associated with coal, where an almost inexhaustible supply is a compelling advantage but where overall economics are poor in the near term. However, carbon monoxide and hydrogen are readily derived from natural gas offering decided economic advantages for the near term with the possibility of a longer term shift to coal if needed. This marriage offers new challenges and versatility for the step by step replacement of oil during the next energy generation. Even in the long-term, carbon monoxide chemistry appears to offer the way to future organic substances which today comprise 90% by value of all the products of man's labor. The central role of carbon monoxide in this view of our energy future results from its production from a wide range of sources, its versitale reaction chemistry and the resulting chemical and fuel product possibilities.

Coal-water slurry fuels can provide the keystone piece of the energy structure we have been building to free our country from its dependence on improted oil. Conservation measures, adjustments in price structure to promote domestic supplies, and the use of alternative and regenerable energy sources have demonstrated a measurable short term effect on our consumption of petroleum products. These efforts will continue to improve our position with time but, unless coal can be introduced relatively quickly into applications which have been heretofore limited to oil fuels, we will continue to see ourselves under an economic threat. To accomplish this, coal must be put into a liquid form with properties which will allow it to be handled and burned in equipment designed for petroleum fuels. Further, it must be made available at a cost comparable to present fuel costs. Coal-water slurry fuels can accomplish this and do it without incurring the high capital costs involved in the conversion of coals to synfuels or in the conversion of industrial plants to handle solid coal fuel. The coal-water slurry fuel is in effect a "poor man's synfuel," a fuel which could make practical the use of coal in oil-fired utility boilers and in industrial heaters, boilers and furnaces which utilize nearly 3 million barrels of oil per day, close to the amount of oil now imported from OPEC nations.

What is an Acceptable Coal-Water Slurry Fuel?

The coal-water slurry fuel is to be used in a variety of industrial and utility applications where petroleum fuels are now used. It will replace distillate and residual fuel oils which have properties that are well speicifed so that they can be purchased and used confidently in equipment designed for their use. Therefore, coal-water fuels will have to have an effective specification that will permit this use with only minor equipment modifications.

Fuel oil properties are adjusted at the refinery by blending to meet purchase specifications. The American Society for Testing Materials (ASTM) has established standards for these fuels which specify physical properties such as flash point, ash content, viscosity, distillation temperature, and specific gravity. Knowledge of these properties confirms the heating value of the fuel and assures the plant operator that he will be able to handle and store the fuel in his equipment. Acceptable coal-water slurry fuels will require the development of a similar specification system based on proven technology for the intended applications.

Preparation of Specifications for Coal-Water Slurry Fuels

A coal-water slurry differs from fuel oil in that it is a suspension of a solid in a liquid while fuel oil is essentially a true liquid. As a result, its physical and combustion properties will vary depending on factors or combinations of factors which need no consideration when dealing with fuel oils. These include the following:

- Type of coal used in preparation of the slurry.
- Coal size, shape, and particle size distribution.
- Amount of ash in the coal after cleaning and sizing.
- Weight percent of coal in the mixture.
- Coal properties after cleaning (density, hardness, etc.).
- Stability of the suspension.
- Chemical additives present to modify viscosity or stability.

Factors such as these will influence the flow and atomization characteristics of the fuel and its flame characteristics, storability, transportation, heating value, and emissions. These factors and characteristics will be important in developing a suitable specification. The final specification will have to describe in detail the information mentioned above and, actually, will be very much like the present ASTM specifications for fuel oil described earlier.

To proceed with the actual preparation of a specification for an industrial boiler or process heater, it will be necessary to determine the amount and composition of ash which can be tolerated in the equipment. The effect of the factors described above will have to be established in combustion tests and in use in various components of the fuel system such as atomizers, pumps, tanks, piping, etc. The result of this process should be the development of specifications for coal fuels which will be functionally equivalent to distillate and residual fuel oils.

Does Coal-Water Slurry Fuel Technology Exist?

Coal-water slurries have been used in tests designed to determine the feasibility of firing this type of fuel. These tests are described in the literature and include work done in the United States, Germany, and Russia. The equipment used was designed for coal firing and test conditions varied considerably. With those reservations, the work demonstrated the feasibility of using coal-water slurry fuel. Experiments ranged in nature from the engineering scale to more fundamental and theoretical studies. The work did not provide a technology base for use in designing slurry systems and not enough information is available to provide assurance that coal-water slurries will perform satisfactorily in equipment designed to fire only oil fuels. For either oil or coal designed equipment, available information regarding the suitability of pumps, piping, valves, and instrumentation is not sufficient to allow prediction of long term operability. A number of research and development tasks must be accomplished before such information can be made available.

Currently, tests are being mounted in the U.S. which will add to the experience already gained. Short tests in oil fired systems have been made which show feasibility but which are not adequate for use in developing specifications.

Retrofit of Oil-Fired Equipment

The replacement of oil by coal is limited severely by factors such as the space available for storing and handling a solid fuel and by the design of the

combustion equipment itself. Coal requires a considerable land area for storage and, since the transportation of coal is not as certain as pipelined oil, extra storage is needed to offset supply interruptions. The presence of ash in coal requires waste handling capability. Pulverizers are necessary to reduce the size of coal to that needed for combustion. These needs also create a type of environmental situation that does not exist with the use of oil, namely, the coal storage and waste areas need to be secure against the leaching of hazardous materials by water runoff from wet coal and from the release of fines to the air by wind action or dust formation in handling.

Plants designed for fuel oil have no provision for such things. Some plants designed for coal use have been converted to oil; the space formally allocated to storing and pulverizing coal is used for other purposes and is no longer available for reconversion. Consequently, the only economical option for retrofit of such plant will be a coal fuel which can be transported, stored, and fired as a liquid.

Combustion equipment designed specifically for oil firing uses a smaller combustion chamber volume and cannot accommodate the longer length of a pulverized coal flame. Even assuming that a somewhat overdesigned unit could handle the pulverized coal, the presence of coal-ash would interfere with heat transfer surfaces as a result of slag formation and fouling. The inclusion of an ash removal system for the combustion chamber itself as well as soot blowers, and perhaps modified tube spacings, in the heat exchanger sections would be necessary. The costs involved in such a brute-force retrofit would be, in most cases, unreasonable. Actually, in many cases technical or space factors would make such an effort impossible.

Two possibilities exist for avoiding the cost of attempting to retrofit using solid coal. One of these is to use synthetic fuels derived from coal such as SRC liquid or the products of other liquefaction processes (formed either directly from coal or from coal derived synthesis gas). The other possibility, and the least cost approach, is to slurry cleaned coal with water to produce a coal-water mixture fuel.

Coal liquefaction processes are costly high-risk ventures which have only moved forward when industry was able to obtain some form of government support for the effort. The scale of any meaningful production plant is such that the costs involved in its construction are not likely to be recovered unless conventional fuel costs increase to disastrous levels. The time required for such construction, the location, and environmental concerns all point to this approach as being unrealistic in terms of our near-term supply problems.

On the other hand, a coal-water slurry fuel can become available for some applications in a matter of a few years while improvements in coal cleaning technology and the development of rigorous specification fuel slurries could lead to widespread adoption of the fuel over a ten year period. The cost of these fuels would start with that of nominally cleaned and pulverized coal, allowing the wide margin between the price of coal and fuel oil to be applied to the development of improved preparation techniques. Coal suppliers would not have to wait for a lengthy process development and plant construction phase to be completed before being able to move coal into this market.

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Research and Development Needs for Coal-Water Slurry Fuels

The key to development of a coal-water slurry fuel lies in the need to establish a specification for these fuels. The factors which influence the physical and combustion properties of the fuel were described in a previous section of this discussion. If is the effect of these factors on the use of the fuel, as well as specific application factors, which have to be studied and evaluated to produce a suitable specification. The nature of these investigations are described here.

1. Stability in Storage and Handling

Questions here include whether or not stability is a necessary specification for particular applications. If the storage tanks can be equipped to cause resuspension of settled slurries, then stability is not an improtant characteristic. Where stability is needed, this may be achieved through study of the interplay of particle size distributions, coal surface properties, chemical additive effects, water and coal quality, and solids concentration. Devices for measuring and monitoring stability may need development. Based on various studies, long-term stability will not be required in most cases.

2. Flow Properties and Transportation

Flow properties of various slurry mixtures must be measured and design correlations developed in order to predict in-plant piping and equipment flow behavior and for development of transportation piping systems. Variables include particle size distributions, the presence of additives, etc. This type of study is relatively staightforward and will be mostly an extension of already available design data.

3. Combustion Control

Atomization characteristics of the coal-water slurry fuel can affect burner design, the combustion of the coal, ash formation, the extent or degree of carbon burnout, heat transfer, and ash slagging and fouling effects. The ash content of the coal can have a significant effect on the combustion properties and the feasiblity of using the fuel in oil designed equipment. A significant R&D effort is necessary in this regard.

4. Mineral (Ash) Specification

The affect of coal minerals on the various boilers and furnaces used in the utility and industrial sectors has to be evaluated in order to establish the optimum degree of coal cleaning required. Both the quantity of ash and the quality (specific minerals present) are important. Essentially, the goal is the development of a specification fuel which could, to a large extent, overcome the variability of coal from different sources.

5. Emissions

Coal-water slurry fuels can minimize the need for emissions control usually considered necessary in using coal. These fuels are expected to be useful in many installations where space is at a premium and emission standards may be very rigid. The key to reduced emissions is in the cleaning of the coal or the adoption of ash removal procedures during or after combustion. Emission levels, including NO_x and particulates, must be quantified.

Conclusions

All the R&D tasks delineated above have a high probability of success. For a minimal investment, compared to coal-derived synthetic fuel technology, a viable infrastructure with new satellite industries can be developed for the coal-water mixture fuel. The fuel, with rudimentary specifications, can be used relatively quickly in oil-fired equipment originally designed for pulverized coal. Building on this limited market, improved specifications will be developed to permit the use of the fuel in oil-designed equipment. The need in this effort will be for the improvement of coal preparation techniques and for an extensive evaluation of industrial fuel capability. Success in this effort could make practical the use of the fuel in the commercial sector as well. With success will come a reduction in oil imports of up to 3 million barrels of oil per day and freedom from the cost and threat which imports entail - a respectable achievement for a "poor man's synfuel."

ASH: A DETERRENT TO THE USE OF COAI

Coal ash, the residue left from the burning of coal, has been considered a burden since man first started to harness the energy in coal to heat homes and provide power for his industrial efforts. Some remember hauling the barrels of ash from the basements of homes heated by coal, adding in the process another type of dust to the coal-dust released when the coal was delivered to homes and apartments. Unfortunately, this romantic example illustrates only one problem presented by the presence of ash in coal - that of dealing with its disposal.

More serious problems result from the effect of ash on the equipment in which it is used, its effect on the products where coal is used to provide energy for their manufacture, and its effect on people if the ash is released to the environment. These effects can be equated to the costs associated with counteracting them; the cost of maintenance, of environmental control equipment and the cost of contaminated products.

Consequently, the rapid displacement of coal by petroleum in the first half of this century was not caused simply by the ease with which fluid fuel could be handled but also by the fact that petroleum is an inherently cleaner fuel containing a relatively minor amount of ash. Coal is currently used to generate about half of the electrical energy supplied by utilities. The plants in which it is used have been designed for coal use and generally for specific coals in order to accommodate the ash levels present in the coal. If coal is to be introduced to the remaining power plants not designed for coal or if coal is to be established again as a significant industrial fuel with a potential for use as a retrofit fuel for existing equipment, then its ash content has to be controlled.

What is Coal Ash?

Ash is comprised of the minerals which became associated with vegetative or carbonaceous materials during their conversion through the ages to coal. They came from sediments deposited with the plant materials, from elements incorporated in the plant structures and from ground water mineral deposits. As a result, they are intimately associated with the organic constituents in coal. Added to these, are minerals in rock adjacent to the seams taken during the mining process. The actual composition and quantity of coal ash depend heavily on the geographic source of the coal but includes the elements silicon, aluminum, iron, sulfur, calcium, magnesium, sodium, potassium, and a number of elements present in trace quantities. Ash quantities range up to 15% or more in selected cases.

It is the composition of the ash which determines the behavior of the ash in various types of equipment. Depending on its composition, the ash of one coal will soften at a temperature which is lower than that of another, leading perhaps to its deposition on hot surfaces in a combustor. If sufficiently hot, ash will form a liquid slag. Depending on its constituents and the manner and conditions under which it deposits in boilers and heat exchangers,

ash can be corrosive. It can also be erosive if carried at sufficiently high velocities through the convection tube banks of a power plant.

In processes such as the manufacture of glass where the direct heating of the product is desired, the ash will come in contact with the molten glass and, depending on the ash composition, cause discoloration or leave imperfections.

The presence of sulfur and its impact on the environemnt is well known. A major part of the current direction in coal cleaning research is the result of the desire to remove sulfur from high sulfur coals.

How Ash Affects Boiler Design

In considering how coal ash will influence the design of equipment, the characteristic behavior of ash associated with conventional pulverized coal firing can be used as a point of reference. If furnace surface temperatures are too high, slag deposition will occur in the furnace. If the temperature of ash particles leaving the combustion section is too high, fouling of the convection sections will occur or, if ash fusion temperatures are too low, the result will be the same. If this takes place, the efficiency or capability of the unit will be reduced. To compensate for the characteristics of the ash, a designer will adjust his design to accommodate the type of coal to be used in the facility.

The velocity of the flue gas through the convection tube sections and the tube spacing have a considerable effect on the rate of heat transfer from the gas to the heated fluid and consequently, the size of the installation for a give heat load. High velocities are desireable. The presence of ash, which can be erosive at high velocities, limits the gas velocity in coal fired boilers and, combined with the fouling tendency, affects tube spacings and the total tube surface required.

The design of oil-fired units varies considerably from coal units. Fuel oil ash levels are quite low and, as a result, the entire oil-fired boiler design can be more compact in regard to furnace volume and tube spacing than is the case for coal fired systems. This means that a boiler or furnace designed for oil firing will not be able to use coal containing large amounts of ash without some major changes in convection section components. More likely, this retrofit option would not be reasonable.

Finally, despite the best design practice in regard to minimizing problems associated with ash, it is difficult to construct a boiler which can accommodate coals from a variety of sources because ash composition, slagging temperature, and volatile mineral constituents will vary from coal to coal. Under the best of circumstances, coal-ash creates a need for increased maintenance and a more complicated overall operational requirement than would be the case for oil-fired components.

The Potential of Ash-Free Coal

If a sufficient amount of ash, including the most troublesome ash components, are removed from coal, the potential for using such coal is reasonably high. The problem of ash slagging and convection section fouling would be eliminated for the most part and, if the length and characteristics of the coal flame could be accommodated in the smaller combustor volume (for coal-water slurry firing there is evidence that this is a reasonable assumption), then the replacement of oil by coal could be accomplished in existing installations. Well cleaned and sized coal would consist of small particles on the order of the size of pulverized coal (80% through 200 mesh) or less. The best approach to handling the finely divided material after cleaning would be as a coal-water slurry suitable for direct firing in essentially conventional oil designed burners. Otherwise, the high surface area and vulnerability to oxidation would make the shipment and storage of the dry fine coal quite hazardous.

The Degree of Cleaning Needed

The amount of ash which could be accommodated in any particular installation such as an industrial boiler, process heater, or utility boiler would vary according to the operating conditions of temperature, heat flux and gas velocity. It is necessary to set an ash specification which would be acceptable for all cases or establish several specifications to accommodate various classes of equipment.

Currently, no such specification can be written for the case in which oil designed equipment in the field is to be fired by coal. The information needed to prepare these specifications is not available. Data and correlations used for the design of coal fired equipment would be useful to estimate allowable ash levels for use in equipment designed for oil firing but a number of tests and some experimental work would have to be done to confirm these estimates. Specifications for fuel oils and operating experience with various fuel oils would provide a lower limit for ash specifications for coal fuels.

Cleaning Technology

Coal cleaning technology has been, for the most part, directed toward the removal of sulfur and some toxic elements. Physical cleaning methods include crushing, screening, froth flotation, heavy media separation, and jigging. These methods result in the production of coals with reduced mineral matter content which are reduced in size to simplify handling and shipping. The coal may then be pulverized at the point of use for firing in power plants. Low-sulfur, low-ash coals receive little cleaning but are sized to some extent for transport. In the cleaning process, some loss of coal occurs ranging from a few percent for minimum cleaning to as much as 60-75% for deep cleaning. New approaches to cleaning are primarily chemical in nature and involve the treatment of physically cleaned coal by various reagent chemicals. Again, the purpose has been to remove sulfur, not necessarily other mineral constituents. Consequently, if the degree of ash removal and the quality (composition) of ash remaining in the coal are to be specified for it to be used in oil fired

systems, a review of cleaning technology and the consideration of cleaning process modifications will be necessary. It is possible that with this modified cleaning objective, more effective and economical approaches to deep cleaning might result.

The Oil-Fired Refit Market

On the basis of the current use of oil in the industrial and utility sectors, primarily distillate and residual fuel oil consumption, the total replacement of oil by coal could amount to about 3 million barrels a day. Of this, 50% would be in the utility sector. In the combined sectors approximately 40% is accounted for by existing oil fired units which would normally not be able to be refit to coal use. With effective coal cleaning and a coal handling and transportation system such as that provided by coal water slurries, much of this industrial and utility oil consumption could be displaced.

SETTING USAID RESEARCH PRIORITIES
for
FUELWOOD CONVERSION and USE
in
DEVELOPING COUNTRIES

A Background Paper
for the A.I.D. Advisory Panel Meeting
January 17-19, 1983

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SETTING RESEARCH PRIORITIES FOR FUELWOOD CONVERSION AND USE IN DEVELOPING COUNTRIES

I. INTRODUCTION AND CONCEPTUAL FRAMEWORK

The international oil crisis and escalating energy costs have heightened interest in the role that fuelwood and other renewable energy sources can play in meeting the energy needs of the developing world. As stated in its Energy Assistance Policy Paper of 1981, AID has two basic policy goals in the energy area: (1) to ease the immediate energy constraints to development in developing countries, and (2) to help those countries make the difficult transition to a mix of energy sources that will sustain their economies in the future. These policy goals were established because the severity of the energy crisis and its impact on economic performance are so great as to threaten the very capacity of many countries to succeed in the implementation of a development strategy of any kind. Thus, AID programs must be sensitive to the range of energy activities that affect development prospects.

The Agency has, therefore, begun a process to identify research priorities for production and use of fuelwood to meet the energy needs of developing countries. In November 1982, a panel of experts was convened to discuss research needs and to recommend priorities for AID research support to help accelerate fuelwood production. A second panel meeting is being convened in January 1983 to provide recommendations for AID research support in the area of fuelwood conversion and use to provide energy for developing countries. This background and issues paper will serve as a discussion framework for the panel members participating in the fuelwood conversion and use deliberations.

The production panel, because it was comprised almost exclusively of those associated with forestry, confined itself to discussions of fuelwood in terms of woody biomass, excluding grasses, residues, solid waste materials and substitution energy sources which are often used to supplement or supplant woody materials for energy purposes. In discussions on conversion and use in this paper, the fuelwood area is broadened to encompass hydrocarbon fuels that can substitute for one another through conversion processes to provide desirable energy products for specific end use purposes. It includes all forms of biomass as well as peat and coal.

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An awareness by the panel of non-hydrocarbon sources such as solar, wind, and small hydro are also important in the discussions in order to encompass all forms of renewable energy in proper perspective.

Within the above broad scope of energy sources, the focus of discussions by the panel in developing research priority recommendations will be in two areas:

1 The full range of energy products from biomass and alternative energy sources that can be used to satisfy traditional energy needs.

2. Energy products from biomass that can provide the energy required for development purposes, such as transportation, commerical, and industrial use.

Biomass can serve two primary roles in meeting energy needs. First, for modern development, biomass can substitute for conventional hydrocarbon fuels, such as wood for oil to fire a thermal power plant. Second, biomass has a major role in serving traditional energy needs of households, both urban and rural, and informal sector commercial/industrial activities. The World Bank estimates that some two billion people, or about 75% of the population of the developing countries, use traditional fuels for cooking. These fuels include firewood, charcoal, crop residue, and animal dung. For informal sector commercial/industrial activities, biomass sources often provide viable energy options. For example, in a rural area without electricity, rice hulls can substitute for diesel as the energy source used to power a rice mill.

The difference in the roles that biomass can play in the modern and informal sectors lies primarily in the management and organization required to make the use of a bioresource economic. In the first case, management and decision making are carried out by conventional energy planners and entrepreneurs in response to energy needs at a "macro" or national level. In the second case, decisions are made by individual households and commercial entrepreneurs in response to market incentives at the local level.

In order to conceptualize some linkages for discussion purposes, Figure 1 illustrates schematically certain relationships between conventional hydrocarbon sources of energy, biomass sources, and renewable non-biomass energy forms. Where biomass sources overlap with conventional hydrocarbon fuels, the cross-hatched section represents substitution between these fuels. This area reflects a technology overlap with respect to conversion processes between some conventional fuels and biomass. For example, gasification and direct combustion technologies for electricity generation apply to coal as a feedstock, as well as to wood chips and agricultural wastes.

Biomass sources in Figure 1 represent all biomass available, such as woody materials and agricultural wastes. These, together with conventional hydrocarbon fuels, represent the total hydrocarbon resource base. Although many thermochemical processes requiring technological research have a similarity irrespective of whether the feedstock base is fossil hydrocarbons or biomass, certain research areas apply only to biomass, such as biological fermentation of agricultural products and wastes to produce ethanol or methane.

The shortage and increased cost of energy have contributed to considerable substitution from conventional hydrocarbon fuels to biomass. Consequently, biomass is attaining status as a valuable commodity for sale as an energy source, and these commercial prospects have created new opportunities for research to provide energy from biomass for development. The amount of substitution of biomass for conventional hydrocarbon fuels varies considerably from country to country, with Brazil being a world leader in this regard.

In Brazil the system of providing transportation fuel as gasoline is being augmented by a national alcohol program. Both sources of fuel are well known, established, and conform to national policies. Management and organizational aspects of national programs such as those which would substitute biomass energy for conventional hydrocarbon fuels are "top-down" in nature, since program decisions are made by government officials and leading private sector enterprises.

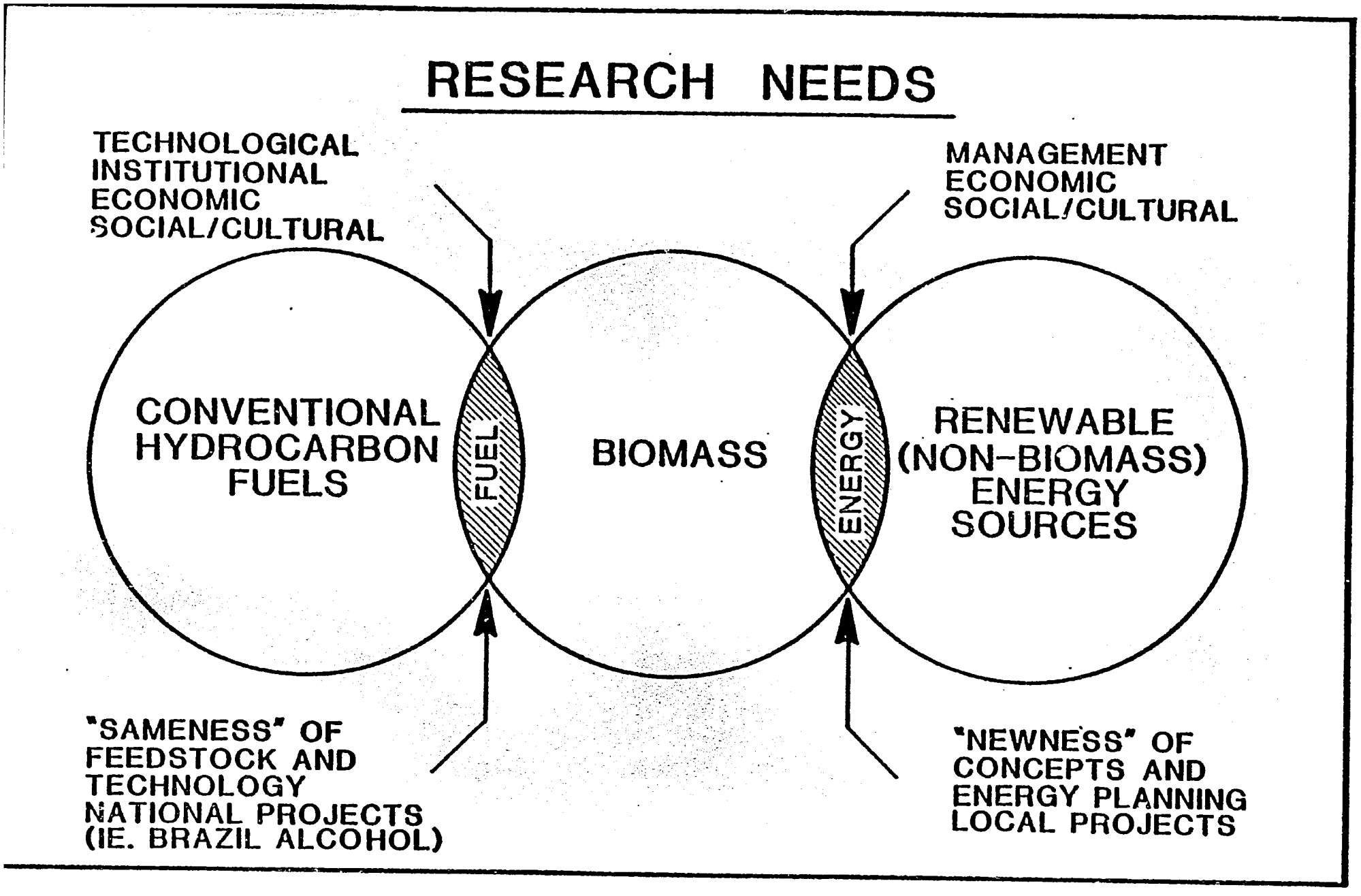

FIG. 1 RESEARCH NEEDS IN ENERGY CONVERSION AND USE AS RELATED TO ENERGY SOURCES

Where both conventional and biomass sources of energy are insufficient, or are prohibitively expensive, non-biomass sources must be seriously considered in the total energy picture with regard to conversion and use. In Figure 1, the third circle labeled "renewable (non-biomass) energy sources" is shown to intersect with biomass to portray certain interrelationships. Here decisions and planning approaches to use solar energy or other non-biomass renewables in place of biomass are likely to be more site specific and local project oriented than are programs to substitute biomass for conventional hydrocarbons. For example, decisions to use solar hot water rather than a wood fired boiler may be made independently by the owner of a local food processor. These local or site specific decisions managed by individuals according to their own best interests could be called "bottom-up" management, as compared with top-down referred to earlier.

The overlapped area between biomass and renewable non-biomass energy sources, which is crosshatched and labeled "energy" in Figure 1, represents a "newness" of concepts and energy planning for local projects where non-biomass energy technology is becoming competitive with biomass. Here common research ground may not be necessarily technological in nature, but rather has management, economic and socio-cultural connotations.

As renewable energy sources become increasingly important, AID has an opportunity to participate in development of renewable energy delivery systems. A delivery system may be defined as the total system required in the delivery of a commodity from source to user. This opportunity begins with the formulation of new concepts for biomass energy production, conversion and use--many of these concepts require research. AID's involvement could extend to providing leadership in promoting these concepts, developing strategies to convince land owners to include biomass as a marketable commodity, providing assistance in arranging credit, and dealing with such issues as land tenure.

In the realm of biomass conversion to end-use energy forms there is a broad range of technological options and subsequent innovations possible in research and

development. In Figure 2* it is seen that conversion technologies for wood include not only direct combustion but also gasification, pyrolysis and acid hydrolysis. The resulting energy forms are heat, steam, mechanical energy, electrical energy, and liquid fuels. When the total range of biomass feedstocks is similarly considered, nearly the same conversion processes can be utilized, with expansion in the range of technologies and opportunities for research. Figure 3 illustrates the conversion processes applicable to various types of biomass resources in addition to wood, and the resulting energy products.

The concept that fuelwood as well as all biomass production and use be exclusively relegated to "energy for survival" as opposed to "energy for development" should be examined by the panel. Annual per capita energy consumption in developing countries is estimated to average 0.25 t.o.e. (tons of oil equivalent), while a satisfactory level for improved health and well-being is considered to be 0.6 to 0.8 t.o.e. The world average is 1.25 t.o.e. These numbers lead some to perceive the problem to be one of increasing the supply of fuelwood with the basic aim of producing enough energy for survival. Clearly this is an important, if not a central, concern, but it contributes little to the cause of development in developing coutries.

It would appear that the goals of AID would be better served if the horizons of fuelwood production and use were expanded to include the energy required for development in addition to that needed for mere survival. This increased role of fuelwood energy would lead to new programs where research could assist in developing technologies to provide energy from biomass. In the eyes of many planners, biomass has had a traditional role of serving a bare minimum of the energy requirements of the poor, but it also can meet a variety of needs of the modern sector of development if converted to suitable solid, liquid, and gaseous fuels. Examples of the ways in which on component of biomass can provide energy for development are shown in Figure 4*. Presented here are selected development oriented uses of the energy available from wood for electricity and power generation, irrigation systems, food and forest product industries, and other industries of importance to developing countries.

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* Source: Talib, Abu, "Wood: An Ancient Fuel with New Potential for Developing Countries," The MITRE Corporation, McLean, VA, 1982.

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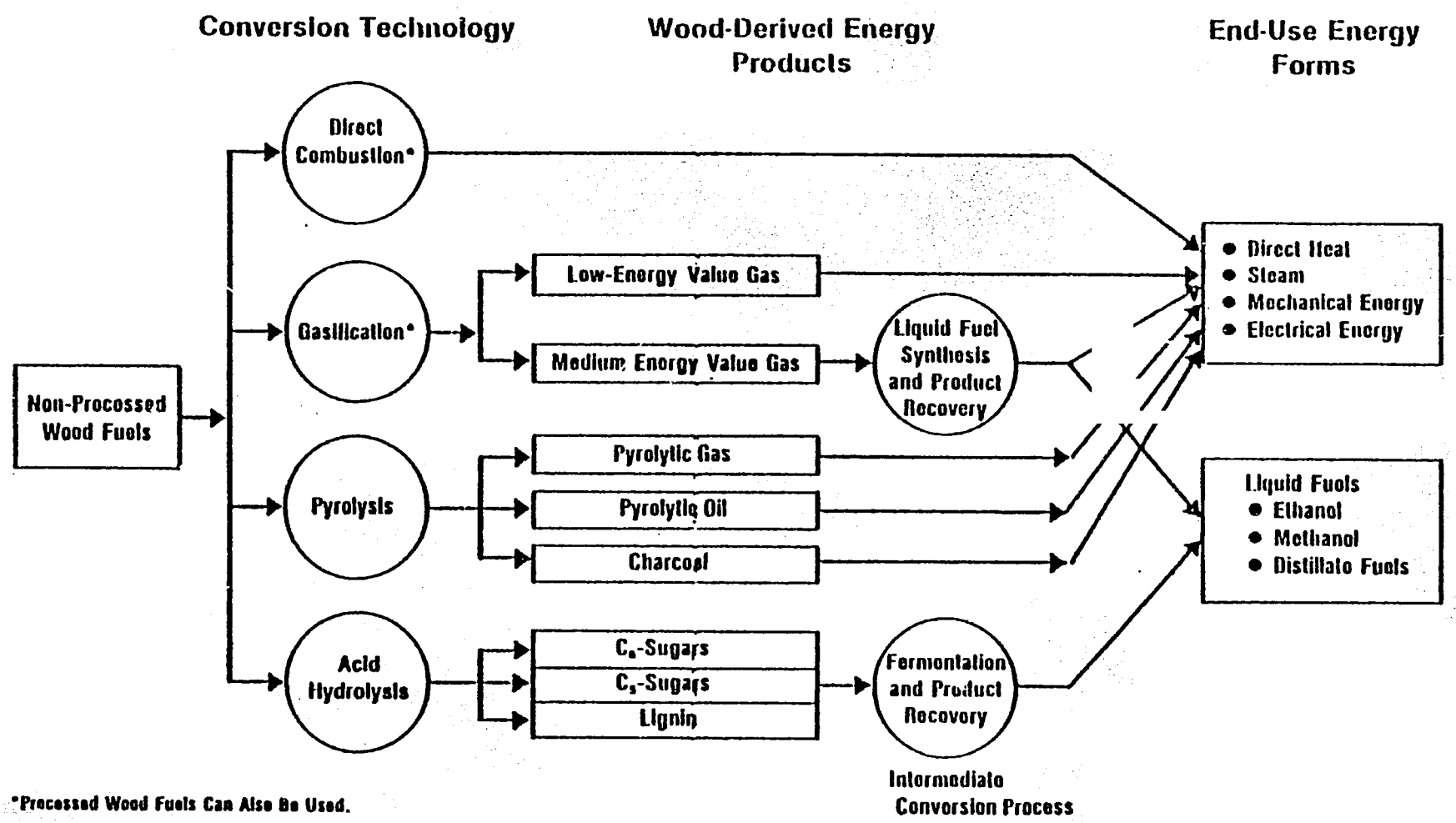

FIGURE 2

USE SCENARIO FOR WOOD AS A SOURCE OF INDUSTRIAL ENERGY

Figure 3

BIOMASS DERIVED ENERGY PRODUCTS

BIOMASS RESOURCE	CONVERSION PROCESSES	ENERGY PRODUCTS
	Thermochemical	
Wood, Forest Residues, Sawdust, Bark Agricultural Residues Wood Wastes Food Processing Wastes Feed Processing Wastes Municipal Garbage	Direct Combustior	Heat Steam Electricity
Wood and Wood Wastes Agricultural Residues Forest Residues, Sawdust, Bark Food Processing Wastes Municipal Garbage	Gasification	Methanol Gaseous Fuels Ammonia Fertilizers Petrochemical Substitutes Synthetic Natural Gas
Wood and Wood Wastes Food Processing Wastes Feed Processing Wastes	Pyrolysis	Charcoal Oil Fuel Gas
Agricultural Residues Manure Sewage Food Processing Wastes Feed Processing Wastes Wood/Wood Wastes/Paper	Direct Liquefaction	Fuel Oil Asphalt Substitue
	Biological	
Agricultural Products (grains, sugar, potatoes) Food Processing Wastes Feed Processing Wastes	Fermentation	Ethanol
Manure Sewage Food Processing Wastes Feed Processing Wastes	Anaerobic Digestion	Methane Electricit Heat Steam

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FIGURE 4

POTENTIAL WOOD ENERGY PROJECTS IN DEVELOPING COUNTRIES

Project \ Application	Electricity and Power Generation	Irrigation System	Food Products Industries	Forest Products Industries	Other Industries
• Wood-Fired Power and Cogeneration Plants	• Rural Electrification	—	• Grain Drying • Fish Processing • Milk Processing • Meat Packing • Bottling Plants and Canneries • Others	• Electric Power for Sawmills • Lumber Drying • Plywood and Veneer Production • Pulp and Paper	• Distilleries and Breweries • Textile
• Wood Gasifiers Air-Blown	• Rural Electrification	• Pumping Water	Retrofit to Existing Oil-Fired Equipment in the Above Food Products Industries	• Electric Power for Sawmills • Retrofit to Existing Oil-Fired Equipment	• Brick Kilns • Calcination
• Wood Gasifiers Oxygen-Blown	—		—	—	• Liquid Fuel Production • Refractory Manufacturing • Lime and Cement Kilns
• Integrated Charcoal Production (State-of-the-Art)	• Utility Power Generation by Char/Oil Slurry	• Water Pumping Using Small Charcoal Gasifiers	—	—	• Pig Iron Manufacturing • Pig Iron and Other Metallurgical Operations
• Advanced Charcoal Production Systems	• Utility Power Generation • On-Site Power Generation	—	• Retrofit of Existing Oil-Fired Equipment	• Retrofit of Existing Oil-Fired Equipment	• Activated Carbon Manufacturing
• Wood-to-Ethanol Plants	—	—	—	—	• Liquid Transportation Fuels • Chemical Industry

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Significant opportunities exist in developing and managing wood alone as an energy source. For example, in Liberia it has been estimated that the waste wood cut for rotation on a single rubber plantation could supply one-tenth of the annual imported fossil fuel requirements of the country. Likewise in Africa as a whole, where wood is the staple source of energy in rural villages, it is estimated that one-tenth of the rain forests could provide enough fuel for all current energy needs of the entire continent if the forests were properly managed and wood distributed to all in need of it.

In summary, research in fuelwood conversion and use should appropriately be based on considerations of alternative ways of meeting the present and future energy demands of developing countries. Research should be aimed at the full range of solid, liquid and gaseous fuels which can be derived from biomass. The expert panel should devote a good deal of its attention to determining whether appropriate technologies are already available for dissemination to developing countries. Discussion should also focus on which characteristics of the system, such as technological, institutional, economic, or socio-cultural are constraints to increased efficiency and wider application of the use of fuelwood. Finally, the panel will develop the role and priorities for research in increasing the efficiency of biomass conversion and use in developing countries.

II. PANEL DISCUSSIONS OF RESEARCH NEEDS IN FUELWOOD PRODUCTION

The November 1982 panel which discussed research needs to stimulate fuelwood production was oriented primarily to forestry, as stated previously. The subject matter was, therefore, confined to forestry research to provide increased quantities of woody biomass for use as fuelwood. A background and issues paper specific to the topic was prepared by Dr. George R. Armstrong, an experienced forest economist. This paper provided information on past and on-going AID programs in forestry and woody biomass production, and is attached as Appendix A to supplement a discussion of AID renewable and alternative energy programs in a later section of this report.

A report on the panel's recommended priorities for research in fuelwood production was prepared by Dr. Armstrong and Olympic Associates Co., and is attached as Appendix B. The panel focused on five research areas, which contained a total of 24 research topics. The five research areas in fuelwood production were as follows:

a. Problem analysis
b. Stock development (selection, improvement and preparation)
c. Forest establishment (plantation establishment and agroforestry)
d. Forest culture and management, and
e. Process implementation

It was the general consensus that although the greatest opportunity for success in woody biomass production is to be found in humid tropical areas, the greatest problems and challenges are in the arid and semi-arid areas of the world. A tabular presentation of the priority ratings assigned to potential research topics is given in Table 1.

A basic working assumption of the conferees was that the wood supply problem is so widespread, local conditions so diverse, and costs of eliminating wood supply shortages so large that a successful attack can be made on the problem only by enlisting strong support of local governments and people. They must be motivated to act, have the technical means for action and have a working environment which

TABLE 1 RESEARCH AREAS AND PRIORITIES IN FUELWOOD PRODUCTION

RESEARCH AREAS	PRIORITY RATINGS		
	High	Medium	Low
Problem Analysis			
Financial & Economic Viability Assessment	X		
Market analyses			X
Assessment of existing forest resources	X		
Stock Development (Selection, Improvement and Preparation)			
Species assessment and Trials	X		
Tree improvement and breeding	X		
Microbiology		X	
Genecological exploration	X		
Improvement of nursery costs and efficiency		X	
Seed treatment			X
Forest Establishment (Plantation Establishment and Agroforestry)			
Land capability and use assessment			X
Land preparation			X
Natural regeneration			X
Seedling transportation and establishment			X
Agroforestry practice assessment	X		
Forest Culture and Management			
Protection			X
Exploration of Silvicultural practices			X
Develop new agroforestry practices		X	
Impact of plantings on soil, water and nutrients	X		
Yield assessment (mensurational research)			X
Process Implementation			
Land use problems			X
Extension problems	X		
Motivation			X
Technology transfer problems	X		
Management problems			X

encourages and guides their activity. Hence, a well-balanced research program must be designed to explore and overcome obstacles to achieveing all three of these goals.

Briefly, among nine high priority areas recognized, species assessment and trials ran first, followed closely by tree improvement and breeding activities. Genecological studies also received high ranking.

The panel stressed research to improve and accelerate information transfer both within the research community and among governments and people of developing countries. They also ranked research leading to effective assessment of current and proposed agroforestry practices among the top nine high priority areas.

Emphasis was on more intensive and frequent use of problem analysis as a critical step in laying the groundwork for programming to increase fuelwood production.

III. CRITERIA FOR SETTING PRIORITIES FOR RESEARCH ON TECHNOLOGIES FOR THE USE OF FUELWOOD

AID is interested in focusing research funding and programming on the technologies and applications that appear most likely, on technical and economic grounds, to meet the energy needs of developing countries. Research should be in areas where the greatest bottlenecks to development exist, where there is the greatest possibility of significant progress (short or long term), and where AID has a special role or competence. There is the need to consider that AID has a limited research budget and that major research and development support must come from elsewhere.

Accordingly, the objectives of the expert panel on fuelwood energy technologies are threefold: first, to assess the need for energy technology innovation and adaptation in meeting developing country requirements; second, to evaluate the extent to which research and development presently address these needs; and third, to recommend specific research priorities for AID support in filling gaps in the present research, development, demonstration and disseminatioon effort on fuelwood energy technologies, considering the criteria for AID support mentioned above.

Futhermore, the panel should consider to the extent feasible, whether the research is of a global nature and thus should be centrally supported within AID, or whether it is more site specific and should be supported within regional or bilateral projects. Recommendations on specific regional or particular country-oriented activities would be welcome. Finally, the panel should discuss the most appropriate mechanisms for carrying out the research, involving developing countries and US institutions.

Setting priorities for research on energy technologies requires a decision framework with an explicit set of criteria. Essentially, the allocation of resources for fuelwood and other biomass energy technologies should be based on their technical status, economic competitiveness, and commercial availability and adaptability. The critical energy situation in most developing countries also focuses attention on meeting needs quickly, and calls for research and investment in technologies which hold the greatest promise in the near to medium term future.

Evaluating biomass conversion technologies and setting research priorities in this area requires a framework in which technologies can be evaluated in the context of a total energy technology system. The complexities of an energy technology system are reflected clearly by recent experience of the U.S. and other economies in their shift to greater reliance on coal for energy in response to the "oil crisis." Assessment of coal resource availablity and evaluation of technologies for all aspects of production (i.e. stripmining), handling and transportation (coal slurry pipelines, port and railroad facilities), conversion (coal gasification and liquifaction), and use have been critical components important in evaluation of the total coal energy system. In addition to assessment of coal resources and coal energy technologies, the decision-making framework includes economic comparison of coal with oil and other energy sources, and evaluation of the ability of users to shift from oil to coal use. For fuelwood and other biomass energy technology systems such as development of cane as an energy source, the establishment of research and investment priorities must be done in a similar policy framework in which all aspects of the system are given perspective.

Evaluation of biomass conversion technologies involves a certain amount of speculation regarding the prospects for scientific breakthroughs on research frontiers as well as the prospects for near term commercialization and widespread adoption of any particular technology. In this sense, the process of setting priorities for research on biomass conversion technologies requires evaluation of the scientific and technical, financial and economic, social, and organizational potential of alternative energy technologies. This process should be set in a risk-return or cost-benefit framework whereby the cost-effectiveness of research in any particular area is an important decision criterion.

The criteria suggested for setting research priorities represent several important perspectives. There are <u>technical issues</u>. To what extent should research be focused on technological components of alternative energy systems? Are the technological components experimental, or proven and reliable? What is the time required for research pay-offs? Second, there are <u>financial and economic issues</u>. Research should focus on these energy systems and technologies that are likely over the near to medium term to be cheaper than alternatives which may be available now or in the near future.

In this respect, the affordability of energy alternatives by potential users is an important consideration. Third, there are social issues. To what extent are energy technologies wanted by the interested beneficiaries? Local adaptation and implementation of energy technologies are paramount prerequisites to success and important concerns in setting program priorities. Finally, the organizational potential of alternative energy technologies is extremely critical to implementation. Is an institutional capability in place? Can the system be replicated, either by being initiated on a local scale or as part of a larger production effort in the host country.

In sum, the following list suggests some criteria which should be used to set research priorities:

1. Applicability to rural and urban needs of developing countries
2. Implementability of research results
3. Potential and timing of research pay-offs
4. Application of research results on global, regional, or country specific bases
5. Cost effectiveness
6. Appropriateness to the energy needs for development
7. Basic as compared with applied research
8. Extent to which research is already being done by other development agencies or by the private sector in response to commercial and other incentives
9. Relationship to AID program guidelines which emphasize:
   a) technical assistance and research
   b) institution building
   c) planning and policy development
   d) limited capital assistance.
10. Relationship to ongoing AID-sponsored activities

IV. BARRIERS TO SUCCESSFUL IMPLEMENTATION OF CONVERSION AND USE TECHNOLOGIES

Research issues relating to utilization of hydrocarbon materials such as biomass to provide energy involve many of the steps identified in Figure 5, which shows basic components of the energy delivery system. Here the resource base is first evaluated as to its potential for providing an economical solution to energy needs. The follow-up steps are then interrrelated through materials handling, pre-treatment, and conversion to forms suitable for final use. There are potential research categories in each step of the system, but some research areas will be more productive than others in near-term as well as long-term return on research investments.

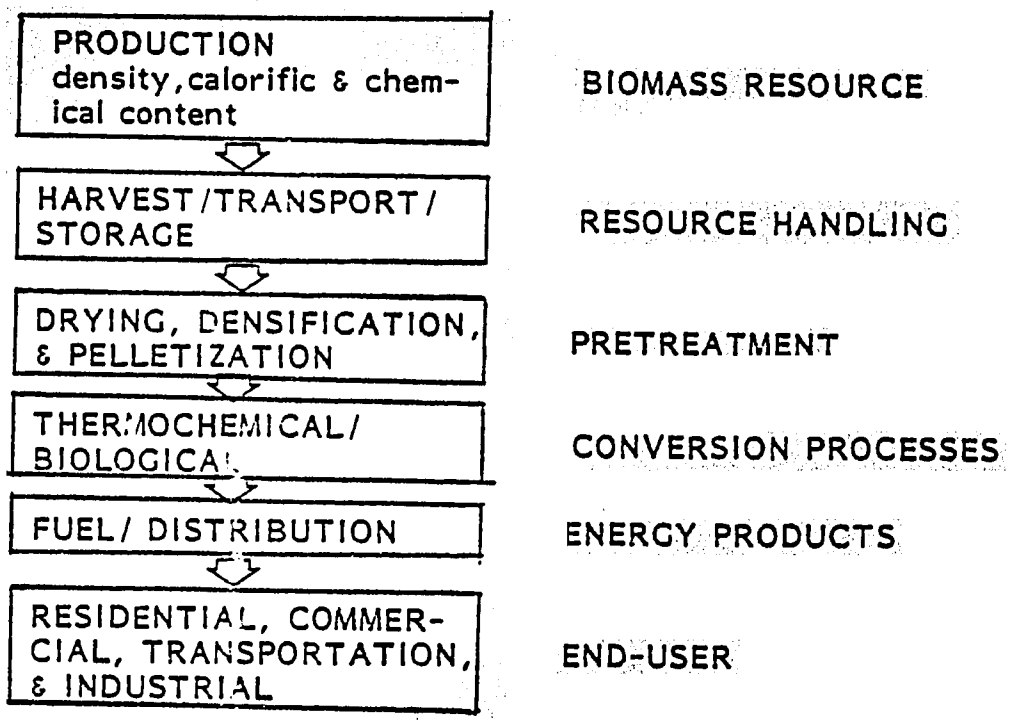
The most important obstacles to the rapid harnessing of renewable energy potential from fuelwood in developing countries appear to lie in the following areas:

a. Technological barriers
b. Institutional weaknesses in energy research planning, programming, and implementation.
c. Economic and commercial viability, and
d. Problems of information dissemination and socio-cultural adaptation.

Technological issues in the choice of conversion processes suitable for a particular developing country or region include the state-of-the-art development of the process, the technical capabilities of local personnel to operate and manage the facility, and the type of energy end products required in developing the country. Although technological issues such as adaptations of existing designs to specific conditions are the most readily identified as research topics, there are other researchable components such as socio-cultural acceptability and adaptability.

Institutional weaknesses present some of the most formidable obstacles to developing countries in realizing the goal of development through conversion and use of fuelwood. While the situation varies from country to country, the most general problem is the absence of national energy plans that can provide a framework for defining the overall role of renewable energy from biomass, for determining priorities among the

Figure 5: FUELWOOD OVERVIEW



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various technologies, and for assigning resources accordingly. A notable example of the successful results which can be achieved through proper institutional planning and programming is the energy program of Brazil in producing alcohol and charcoal. A similar program which appears to be on the way to success is that being launched in the Philippines to produce electricity from biomass. The Philippine energy program, like that of Brazil, is based on a strong commitment and direction taken by the central government to encourage energy production for development from biomass sources.

Because of the relatively high cost of energy from conventional sources in developing countries, the economics of a fuelwood energy program may be more attractive there than in the developed world, particularly for rural applications. Typically, the cost of electricity from large thermal or hydro electric power stations supplying a national or regional grid may be nearly the same in a developing country as in a developed country. However, in many cases only a small percentage of the population of developing countries is served by a grid, especially in rural areas. Where the grid does not reach, the conventional alternative for meeting small scale needs is usually diesel-generated power, which may cost three to five times as much as grid supplied power. Therefore, a fuelwood energy source could be economically competitive where rural energy is prohibitively expensive, and where energy planning is oriented to development and subsequent increased capacity to pay for the energy produced.

A case in point where a government policy decision favored commercialization of biomass as an energy source can be seen in the recent history of market competition between kerosene and fuelwood in Indonesia. There, the government was subsidizing the cost of kerosene for rural energy needs. The subsidy resulted in kerosene being sold for much less than its true value, the government spending huge sums to support the subsidy, and the prevention of growth of a fuelwood economy by the artificially low kerosene prices. Three years ago the subsidy on kerosene was removed, causing a three to four fold rise in price over a two year period. This led to an increase in the price of fuelwood and prompted renewed interest in its production as a marketable commodity to compete with kerosene. New opportunities are therefore now available in the area of the delivery system, where the private sector has alternatives and choices regarding production, conversion, distribution, and

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uses of biomass energy. New perspectives also result with regard to social welfare versus development when considering the energy program in Indonesia

Problems of information dissemination and socio-cultural adaptation are not confined to developing countries, but rather are common to both developed and less developed nations. Lack of information exchange regarding the technology of energy conversion and use is usually greater in developing countries, however, since there is usually a less well developed cadre of technical personnel and system of extension. Much of the impact of research in fuelwood conversion and use will depend on local capability to make the results available throughout the country, on the capacity to adapt the technology to the needs, capabilities, economic and technical achievability, and life style of the people, and to replicate the technology widely through appropriate entrepreneurial mechanisms.

V. RESEARCH TOPIC AREAS FOR PANEL CONSIDERATION

Research areas and topics in a subject as broad as fuelwood conversion and use can be almost unlimited because of the diversity of feedstocks. Even a single hydrocarbon energy source such as coal, as attempts are made to encourage a coal energy economy in many countries, has stimulated massive research efforts in a host of topic areas. When we consider the many potential feedstocks involved and technologies to be examined in a fuelwood or biomass energy economy, the potential research topics are increased manyfold.

To focus on primary issues and to maximize the efficiency of the panel, suggested research categories are limited to 14 broad subjects in this background paper. From one to ten research topics are listed below within each category. Panel members are encouraged to suggest modifications to the categories and/or topics, especially in their areas of special knowledge and expertise. Any such modifications will be incorporated into the agenda at the beginning of the panel meeting. Below is a brief description of each suggested research category.

The highest priority recommendations of the panel should be quite selective in order that there be a significant degree of assurance that they can be implemented within resources available to AID, considering also the other program and policy priorities of the Agency.

1. Problem Analysis

   This category of research is an assessment of the prevailing conditions which bear on national decisions involving fuelwood conversion and use. The data base necessary to assess realistically the present and future roles of energy from fuelwood is often lacking in developing countries. There have been few efforts to evaluate carefully the resources required and potential results of energy production from both biomass and renewable non-biomass sources. Systematic efforts to fill the most serious data gaps are prerequisite to the rational selection of development priorities and sound program planning.

Topics include:

a. Marketing

(1)Biomass sources

(2)Substitute non-biomass sources

b. Distribution

c. Social and economic issues

d. Delivery systems

e. Commercialization

2. Harvesting and Transport Methods

Harvesting techniques are determined by the type of biomass or fuelwood used as feedstock, as well as local factors such as the amount and availability of local labor and the socio-economic decisions to operate in labor intensive or equipment intensive modes. Among the factors to consider regarding transporting fuelwood are unit costs, multiple handling, machinery/equipment requirements, and transportation distances.

Research topics include:

a Harvesting equipment design, local vs. imported models

b Economics of labor intensive vs. equipment intensive operations, fuel considerations, size of material being handled

c Field trials of candidate harvesting equipment, duration, size of equipment

d. Transportation equipment design

e. Economics of candidate transportation equipment

f Cost of haul from source to processing to distribution.

4. Processing/Storage

Often fuelwood requires pretreatment prior to storage, such as size reduction or drying. Since pretreatment requires energy, it is minimized and used only when necessary. Storage may be required to maintian an even flow to processing or to enable removal of a biomass crop from its site to allow a succeeding rotation. Topics in this area include:

a. Effects of moisture on storage characteristics

b. Measures to avoid decay and loss of biomass by insects

c. Cost of pretreatment vs. benefits in processing

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d. Storage volume and costs for various modes of operation of conversion facilities.

e. Storage related issues - location to minimize moisture, duration, methods of enhancing Btu content, others

4. Density and Calorific Content

As a general rule, the more dense a biomass feedstock the higher is its energy value. Density and calorific values are therefore important in assessing the worth of biomass for energy purposes, and can be used in determining optimum harvesting time for maximum energy yield. Research topics include:

a. Development of low cost analytical devices for measurement

b. Development of field measurement techniques on unharvested biomass

c. Assessment of candidate biomass feedstocks.

Analytical determination of the chemical content of biomass feestocks is important in determining the suitability of those feedstocks for combined energy and by-product uses. Operational control of certain conversion processes is carried out by means of chemical analyses, such as fermentation processes. Among potential research topics are:

a. Chemical analyses required for development of improved conversion processes

b. Chemical analysis for process control and analysis of product energy forms

c. Control operations used in waste management

6. Densification and Pelletization

Densification is the process of compacting biomass particles, usually by mechanical means such as extrusion or various forms of compaction. Forms of densification are pelleting, cubing, briquetting, extrusion, and rolling-compression. Densified fuel can be used for gasification, central heating, wood stove fueling, and pyrolysis. The process requires energy, but it increases the number of potential uses and allows economical transport over greater distances. Topics include:

a. Development of improved densification equipment

b. Improvement in densification techniques as pretreatment to conversion requiring specific physical characteristics, dimensions, and thermal properties.

c. Development of densification combined with additives to improve monetary value of selected feedstocks for fuelwood purposes

7. Direct Combustion

Direct combustion is one of the most efficient methods of recovering energy from biomass, and the efficiency is related not only to the moisture content but also to the size and design of the combustion facility. Open burning for cooking purposes gives the poorest efficiency. Stove design as well as the type and size gradation of feedstock are important in the success of direct combustion. Although there is nearly a continuous spectrum of combustion unit sizes, the three major sizes are household type stoves, commercial and industrial burners, and dendrothermal power plants. Research topics include:

a. Improved stove design
b. Specific stove design for specific biomass feedstocks
c. Pretreatment and stove design for use of low grade fuels
d. Improved and low cost materials of contruction for stoves
e. Improved densification or other pre-processing for boiler applications
f. Improved drying processes
g. Materials handling and storage problems at dendrothermal plants
h. Systems analyses to determine optimum dendrothermal plant sizes for sustained operation under various conditions of climate, plantation practices, and other variables
i. Fuel products and distribution, co-generation
j. Pollution control aspects of furnace design

8. Charcoal Production

Charcoal is produced during thermochemical conversion of fuelwood when oxygen is rarified to produce an incomplete burn. The fuelwood is decompsed into combustible gas or oil and charcoal. Charcoal is much more economically transported and handled than an equivalent amount of wood, and is therefore often widely used as a household fuel in urban areas, while firewood may used by rural populations closer to the source of supply.

Steel plants use charcoal in place of coke in Brazil, Australia, and the Philippines. Charcoal is also used for many other manufacturing and commercial purposes. Production methods are often crude and inefficient, and many developing countries are not taking advantage of the opportunity of developing a charcoal energy economy. Research topics in this area include:

a. Technical and economic analyses of available charcoal making processes and usefulness for developing countries
b. Improvement of low investment cost brick beehive kiln process: increase of charcoal yield, by-product recovery (tar), productivity
c. Measures to decrease the investment needs for the continuous carbonization process for total by-product recovery and high productivity
d. Charcoal properties vs. carbonization parameters and use
e. Improvement of existing charcoal utilization processes for cement production, steam production, pig iron production, process heating (improvement of grinding, pneumatic transport, burning, etc.)
f. Methods to improve capture and use of gases and tars derived from the charcoal manufacturing process
g. Evaluation of economics and socio-cultural aspects of developing charcoal energy economies. This includes consideration of the marketing and distribution system.
h. Methods to determine social acceptance of charcoal as a potential substitute for kerosene for cooking in those countries where appropriate

9. Pyrolysis

Pyrolysis is the thermal decomposition of solid hydrocarbon fuels in an air-starved atmosphere to produce medium Btu gas, an oily residue, and char. Comparing pyrolysis with gasification, the lower temperatures and less complete combustion of pyrolysis favor the production of oil and char at the expense of gas formation. The quality of the pyrolysis products varies with operating temperature and other parameters, and it is difficult to obtain consistent quality energy products from small and inexpensive pyrolysis units.

The oil and char produced in pyrolysis units are generally of low quality and not easily used as fuels. The oil is viscous and corrosive, and the char has less fuel value than charcoal. Research topics in the area of pyrolyis include:

a. Improved controls for operation of small units
b. Improved gas clean-up procedures
c. Experimentation with additives to the oil and char products so as to render them more useable as fuels
d. Improved mechanism to feed biomass into the pyrolysis unit

10. Gasification

Gasification is the thermal decomposition and partial combustion of solid hydrocarbon fuels in the presence of a limited supply of air to produce low Btu gas, or producer gas. After proper clean-up, the gas produced is suitable as fuel for internal combustion engines, furnaces and other industrial uses. Gasification is an old and established technology, with producer gas used commonly for street lighting since 1850. Gas powered engines were used regularly during the petroleum shortages during World War II, but the availability of inexpensive fossil fuels led to a virtual abandonment of gasification technology in the post-war era. Research and development of gasifiers has accelerated as a result of the oil crisis of the mid-1970's, and the technology is now gaining rapidly in momentum. Research topics include:

a. Improved methods of gas clean-up for use in internal combustion engines
b. Improved design of fluidized bed units for large-scale operation
c. Improved design of small gasifier systems and gas clean-up trains to provide minimum-maintenance operation of internal combustion engines
d Improved construction materials to minimize corrosion of gasifier and associated gas-using facility
e. Operational procedures to avoid explosive producer gas mixtures and carbon monoxide inhalation

II. Liquid Fuel Technologies

Methanol, or wood alcohol, is produced by gasification of hydrocarbon materials, followed by a catalytic reaction between carbon monoxide in the gas with hydrogen. Early plants used gasification of wood to provide feedstock gases, but in recent practice natural gas has been the most common source. Recent research and development in the petroleum industry is resulting in new and lower cost processes to produce methanol.

The technology of ethanol production by fermentation is well known and practiced throughout the world. At the present time it is perhaps the successful method of converting biomass to an alternate energy source for powering gasoline engines. The program in Brazil is well known. Brazil is reputed to be the only country in the world where vehicle engines specifically designed to use hydrated ethanol are available. Although sugars are the preferred substrate for ethanol fermentation, starch can be used with an intermediate hydrolysis reaction. Cellulose is also amenable to conversion to a satisfactory substrate with more complex processing.

Direct liquefaction of woody biomass has been demonstrated, but the results to date have not been sufficiently successful to pursue the matter further at this time. Research topics in the area of liquid fuels include:

a. Monitoring methanol technology to take advantage of breakthroughs in ongoing research which would improve financial and technical feasibility of the process
b. Development of thermotolerant yeast strains, and other alcohol producing organisms which are productive at higher than normal operating temperatures.
c. Distillation column design for operation at moderately high cooling water temperatures
d. Developing low cost ethanol plants using local materials and equipment
e. Improving internal combustion engines to operate on hydrated ethanol and ethanol/gasoline mixtures

f. Developing ethanol fermentation processes for those feedstocks which are most productively grown in each specific developing coutry.

g. Developing the marketing and distribution system which will be required as a national ethanol program unfolds

h. Generation of data input to government decision makers regarding the desirability and/or scheduling of a large scale ethanol program in those countries where appropriate

12. Anaerobic Digestion to Produce Methane

Anaerobic digestion of biomass materials produces a medium Btu methane/carbon dioxide mixture. The technology of conversion is simple and inexpensive, and well suited for implementation in developing countries. Potential feedstocks include animal and human wastes, plant materials, food processing wastes, and indutrial wastes. The gas mixture, often known as biogas, is relatively clean and after the removal of trace concentrations of hydrogen sulfide, can power internal combustion engines. Because of its suitability for both domestic and industrial uses in developing countries, implementation of biogas plant technology has been active throughout the world. A principal problem has been the use of plant designs which require substantial amounts of daily operating labor, which discourages owners from continuing the use of the plants. Research topics related to anaerobic fermentation include:

a. Digester design based on gravity flow using little if any operating pumps or equipment such as stirrers

b. Evaluating the potential of using oversized unheated plants

c. Developing low cost designs such as lagoons with gas holders

d. Evaluating the use, as substrates, of those biomass materials most commonly available in each developing country

e. High solids (dry fermentation) technology

13. Alternate Biomass Feedstocks

Because of the importance of the entire spectrum of biomass feedstocks to meet energy demands, a separate category is listed here to call out research topics which would lead to increased utilization of these resources in addition to woody biomass.

In addition, and more within the interest of this panel, is the delineation of research on these non-woody biomass materials which would lead to improved conversion and use as energy sources. Research topics include:

a. Maximizing the growth of grasses, to be managed and used as energy crops

b. Evaluation of agricultural residue primarily from the standpoint of potential energy resources, developing the most suitable conversion technology for each type of residue, commensurate with local conditions

c. Developing energy uses for local solid wastes, ranging from incineration of low moisture content material to anaerobic fermentation of moist and sludge type wastes. This topic would also include research on densification and pelletizing of solid wastes for use in direct combustion

14. Non-Biomass Sources of Energy

Non-biomass sources of energy include solar, wind, small scale hydro, and other sources such as geothermal and photovoltaic. All these sources have potential roles to play in meeting energy demands, and their use would diminish the demands placed on biomass and conventional hydrocarbon sources. It is therefore appropriate to approach the interrelated effects on the basis of research evaluations. In this case the studies would be primarily the development of management strategies and models which would show the economic impact of non-biomass energy development. Socio-cultural aspects of potential development of these sources could also be studied. Related research topics include:

a. Determination of planning, program, and management strategies which would encompass the use of non-biomass sources of energy where these are appropriate in a developing country.

b. Economic models to determine the impact of non-biomass renewable energy sources

c. Socio-cultural implications of utilizing those non-biomass sources of renewable energy which could appropriately displace conventional hydrocarbons and biomass in the future.

VI. AID FUELWOOD ENERGY ACTIVITIES

Within the context of AID's overall mandate to promote economic development and political stability in certain developing countries, energy assistance has become a priority Agency activity over the past seven or eight years. AID has responded rapidly to Congressional directives, embodied in amendments to the Foreign Assistance Act of 1961, that authorized AID to assist developing countries in energy planning and analysis and in utilizing new energy measures and technologies. Descriptions of fuelwood projects support by AID have been provided by Dr. George Armstrong in the attached background paper for the November 1982 panel meeting on fuelwood production, and are not repeated here. The material which follows is primarily an analysis of the AID program direction and focus as it has evolved to the present time.

Past Congressional directives, specifically the amendments to the Foreign Assistance Act in 1977 and 1979, have called for greater attention to decentralized, renewable energy sources for the rural poor as well as on fuelwood depletion and development of indigenous fuel resources.

Since 1977, AID has built a renewable energy program which is one of the largest and most diversified among development institutions. AID expenditures on energy projects in general, (excluding power generation projects) increased from $26.8 million in FY 1978 to nearly $140 million in FY 1982 (see Table 2). Similarly, funding of energy-related projects and renewable energy projects has risen from $20.5 million in FY 1979 to $86.5 million in FY 1982 (see Tables 3-9).

While the renewable energy program has expanded quickly, still much of the effort has been devoted to mobilization of AID's capability to provide energy assistance and to formulation of an energy assistance strategy. An Office of Energy was created in 1978 to serve as the center for energy assistance planning and coordination and the repository of expertise and technical services for use by all AID components. Energy professionals have been added to the four regional bureaus and resident energy advisors have been assigned to many field missions. Energy policy statements have been issued by the Office of Energy periodically, advising the missions on the types of energy activities considered appropriate for assistance. In March, 1979, the statement recommended assistance programs designed to:

Table 2

AID ENERGY ACTIVITIES* BY BUREAU

	FY 1979		FY 1980		FY 1981		FY 1982 (estimated)	
	# of Prj+	$M	# of Prj	$M	# of Prj	$M	# of Prj	$M
AFRICA	7	6.0	15	12.1	16	14.0	16	13.6
Development Assistance	7	6.0	14	11.4	14	11.0	14	10.0
Economic Suppoort Fund	-	--	1	.7	2	3.0	2	3.6
ASIA	5	5.0	8	3.8	5	5.8	13	68.2
Development Assistance	5	5.0	8	3.8	5	5.8	12	57.2
Economic Support Fund	-	-	-	-	-	-	1	11.0
LATIN AMERICA & CARIBBEAN	12	6.6	15	8.1	15	18.0	19	25.5
Development Assistance	12	6.6	15	8.1	15	18.0	19	25.5
Economic Support Fund	-	-	-	-	-	-	-	-
NEAR EAST	5	2.0	6	17.6	2	2.8	6	19.6
Development Assistance	4	1.7	3	1.2	2	2.8	2	1.6
Economic Support Fund	1	.3	3	16.4	-	-	4	18.0
SCIENCE AND TECHNOLOGY	7	7.3	16	9.0	11	11.3	11	12.6
Development Assistance	7	7.3	16	9.0	11	11.3	11	12.1
Economic Support Fund	-	-	-	-	-	-	(1)#	0.5
PROGRAM POLICY COORDINATION		-	-	-	1	.05	1	.2
Development Assistance	-	-	-	-	1	.05	1	.2
Economic Support Fund	-	-	-	-	-	-	-	-
TOTAL	36	26.8	60	50.7	49	52.0	67	139.7
Development Assistance	35	26.5	56	33.6	47	49.0	59	106.6
Economic Support Fund	1	.3	4	17.1	2	3.0	8	33.1

* Excludes power generation projects.

+ Number of projects funded each year (may be continuing projects).

$500,000 from ESF allocation to an existing project included in eleven projects above.

1. develop energy systems less dependent on imported oil and based to a greater extent on indigenous energy resources;

2. facilitate a long-term, global transition to substantial use of renewable sources of energy;

3. encourage alternatives to unnecessary or economically unsound commitment by LDC's to nuclear power systems; and

4. provide improved technologies for production and efficient use of energy based on renewable resources at the community and family level.

More recent energy strategy statements have not reflected any major policy shifts. However, the most recent statement reflects a more sophisticated approach in which the interdependence between traditional and commercial energy problems and between rural and urban energy needs was explicitly recognized.[1] Also, the statement calls for a more coordinated "systems" approach to future technlogy-related projects through analysis of economic, social, environmental, and institutional as well as technical factors. This approach emphasizes energy needs and end uses, rather than the hardware, as the driving force. Fuelwood energy development is identified as a priority area in this statement.

Stemming from the broad energy policy goals, the activities considered appropriate for funding relate to four basic program areas: 1) energy analysis, planning and policy development; 2) training and institutional development; 3) technology systems development, including research, demonstration and site testing of new energy systems; and 4) increasing energy supply and improving the efficiency of energy use.

The Office of Energy has shown an inclination in the past towards testing and applying renewable energy hardware, since most projects supported by the Office in its first years were devoted to adapting "off-the-shelf" technologies for developing country application. However, this hardware orientation has been reduced substantially.

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1 AID, "Energy Sector Strategy Paper," outgoing telegram, Washington, D.C., December 1982.

Currently (FY 1982), approximately 30 percent of the Office's budget supports training and institution-building activities.

AID's energy assistance program has been designed in view of the energy programs that have been adopted by other development agencies as well as the activities that can be pursued by the private sector. AID has tried to structure its energy program such that it complements rather than substitutes for other activities and programs. In view of AID's role vis-a-vis other donors, AID's energy program consists primarily of technical assistance for a wide range of energy projects, both non-renewable and renewable, with capital assistance limited to fuelwood, small hydropower, and to a lesser extent, other renewable energy activities.

AID devotes major attention to fuelwood production, both directly and by supporting multiple-use forest management activities. The Agency sees its role in promoting fuelwood production primarily as one of supporting experimental projects, village or family woodlots, social forestry projects, and multiple-use forestry management. The direct financing of large-scale fuelwood plantations is seen to be mainly in the province of the multilaterial development banks.

Similarly, the multilateral development banks, other assistance agencies, and the private sector are expected to play the major role in financing energy production from new renewable energy sources (e.g., biomass conversion, direct solar, wind) when the technologies and their applications have been proven. AID limits its involvement in this area primarily to provision of technical assistance for testing and demonstration of new technologies, training, institution-building, and planning. However, some capital assistance is provided by AID on fuelwood production and use projects, especially through the Economic Support Fund.

AID is actively supporting programs and projects to increase energy efficiency in developing countries, mainly programs to develop and promote improved cooking stoves, more efficient kerosene stoves and lamps, and more efficient charcoal manufacturing techniques.

AID's overall approach to renewable energy system development in developing countries might be broadly characterized as exploratory, cautious, and broad based. AID has not become wholeheartedly commited to any one alternative energy source (except perhaps firewood), technology option, or aspect of an energy delivery system. By and large, the agency has elected to devote resources to problem analysis, research on alternative energy technology systems, pilot programs, and demonstration projects, rather than to a targeted large scale effort to immediately meet energy needs. The cautious approach that AID is pursuing has the goal of providing a sound technical, economic, and institutional foundation for future work of AID and developing country governments so that larger scale projects can be properly planned and executed. Part of the thinking behind this approach is that AID will fill only a temporary role in introducing new energy technology in developing countries until its infrastructure building programs have advanced to the point where host countries do the work themselves.

AID's focus on firewood production and fuelwood technology development is an exception to this generalized characterization of AID's energy program. Firewood production and fuelwood energy system development are specific priority areas of AID's energy program. AID has a large number of fuelwood projects planned or already underway. It is in the fuelwood energy area, however, that the AID energy program has an apparent weakness. In particular, fuelwood production projects are often not effectively built into AID energy programming. For instance, many global, regional, and national energy assessments report that firewood and other biomass energy sources supply somewhere from one-half to three-fourths of energy requirements. These assessments frequently identify deforestation and other environmental problems and go on to recommend forestry-related fuelwood production programs and projects. However, these fuelwood production recommendations are made without explicitly linking fuelwood production back to energy in terms of the extent to which forestry projects and programs can or will contribute to national energy supplies. The recommendations also often lack explicit attention to the range of marketing, commercial and other considerations necessary to integrate fuelwood production within a complete energy delivery system-which includes all aspects of production, marketing, conversions and end-use.

In a similar vein, numerous forestry projects add on a fuelwood component that has not been adequately elaborated in terms of effectively meeting end-use requirements. Some fuelwood technology R&D components may even be included. However, to date, only a few projects have been geared to comprehensive fuelwood energy system development. The Philippines Energy Development project is a noteworthy example of comprehensive projects of this type and is briefly described later.

The current energy program strategy "thinking" at AID, as reflected in S&T Office of Energy and in the energy offices of the regional bureaus, emphasizes a "bio-resource systems" approach in the planning and programming of energy projects. This approach involves organization of project components to satisfy a desired market need by the production of a fuel through conversion of a biomass resource to a useful biofuel. The biomass is obtained either through cultivation of a special crop such as sugar cane or trees which are dedicated to energy production or through processing of a waste such as crop residues or industrial by-products. The planning of a bio-resource energy system requires that particular attention be given to the linkages between system components. For example, the relative locations of areas of biomass production and biofuel consumption strongly influence the biofuels' market penetration and hence the overall economic feasibility of the system. Establishing woodlots or building biogas generators as separate activities by themselves will not automatically lead to development of significant new energy sources.

Much of the above strategy perspectives have emerged from the Bio-Energy Systems and Technology project launched by the Bureau of Science and Technology's Office of Energy. To some extent, this approach has been adopted in the formulation of specific energy projects and programs at the field missions and regional bureaus.

The energy projects (excluding power generation) supported by the regional bureaus, the offices of the Bureau of Science and Technology, and the Program Policy Coordination Bureau are summarized in Tables 3-9. Defining which projects can be classified as an "energy project" for inclusion in each bureau constitutes a problem; some discrepancies between what the bureaus report as their "energy" projects and what is presented in the tables result from the fact that firewood energy is but one component of multi-purpose forestry and rural development projects.

Asia Bureau

Asia's energy sector program has shifted from one dominated by rural electrification projects to a more balanced program in alternative energy development, fuelwood production and conversion, and natural resource management.

Among alternative energy technologies, combustion, carbonization and gasification are priority areas for research and development in AID programs, while liquid fuels and anaerobic digestion are lesser priority technologies. Biomass, coal and small hydro energy resources are the emerging focus of Asia energy programs.

The Philippines Rural Energy Development Project and the National Energy Laboratory project in Indonesia are centerpiece projects of the Asia energy program.

The Philippine project is the most ambitious with three separate components:

1) financing of three 5 megawatt dendrothermal generating plants for rural electricity cooperatives;

2) development of alternative energy sources for water pumping -- 1000 wood gasifiers based on small community woodlots; and

3) technical assistance for charcoal production.

The Indonesian National Energy Laboratory is an institutional development project aimed at building research capability for technology assessment and evaluation, demonstration, and promotion through the private sector of biomass conversion technologies. An 11.25 million dollar loan and $500,000 in grant funds from AID will support research, development and testing laboratories which will promote cost effective equipment, processes, and products that make maximum long-term use of Indonesia's energy sources.

Africa Bureau

The Africa Bureau has been very instrumental in steering world attention to the fuelwood crisis in Africa, as well as in shaping AID's energy policies and programs

Table 3

ASIA ENERGY PROJECTS*

Country/Project Title	FY79	FY80	$000's) FY81	FY82 (estimate)
Energy-related Forestry Projects	-	751	4,290	39,856
India-Madhya Pradesh Social Forestry	-	-	3,000	10,000
India-Maharashtra Social Forestry	-	-	-	27,300
India-Agricultural Research	-	-	-	720
Indonesia-Citanduy Rv. Basin Dev. II	-	00	300	800
Nepal-Resource Conservation & Utilization	-	270	990	1,036
Sri Lanka-Resorestation & Watershed Mgmt.	-	435	-	-
Thailand-Mae Chaem Watershed Development	-	46	-	-
Renewable Energy Projects	3,875	2,100	980	18,240
India-Alternative Energy Resources Dev.	-	-	-	5,000
Indonesia-Science & Tech./ Research Training	60	500	-	-
Indonesia-Puspiptek Energy Lab-	-	-	-	1,950
Nepal-Rural Area Development-Rapat.	315	100	980	290
Thailand-Renewable Non-Conven. Energy	3,500	1,500	-	-
Philippines-Rural Energy Development+	-	-	-	1,000
Other Energy Projects	600	500	500	9,100
Indonesia-Energy Manpower & Training	-	500	500	-
Indonesia-Energy Planning for Dev. II	600	-	-	1,000
Thailand-Micro/Mini Hydroelectric	-	-	-	8,100
Asia Regional Projects	500	440	-	1,000
ASEAN	-	440	-	-
Energy Development & Support Centers	500	-	-	-
ASEAN-Energy Cooperation in Development	-	-		1,000
TOTAL	4,975	3,791	5,770	68,196

* Excludes power generation projects.
\+ Financed from Economic Support Fund.

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Table 4

AFRICA ENERGY PROJECTS*

Country/Project Title	FY79	FY80	FY81	FY82 (estimate
	($000s)			
Forestry-related Energy Projects	3,435	2,995	2,952	1,286
Gambia-Forestry	1,181	-	-	-
Niger-Forestry & Land Use Planning	-	332	173	-
Senegal-Fuelwood Production-Phase I	1,404	700	730	600
Senegal-Africare Forestry	-	126	-	-
Senegal-Africare/PC Village Woodlots	-	212	-	-
Upper Volta-Forestry Education & Dev.	525	1,350	1,730	-
Burundi-Bururi Forest	-	-	-	686
Mauritania Renewable Resources Management	325	275	319	-
Renewable Energy Projects	1,600	4,207	4,247	3,876
Kenya-Renewable Energy Development	-	3,482	1,317	-
Lesotho-Renewable Energy Technology	600	-	-	-
Mali-Operation Mils-Phase II(solar pumps)	-	-	-	770
Mali-Renewable Energy	-	-	930	470
Sudan-Rural Renewable Energy	-	-	1,000	1,057
Botswana-Renewable Energy Technology+	-	725	1,000	1,579
Other Energy Projects	-	3,600	4,847	3,197
Burundi-Alternative Energy Peat II	-	2,000	2,000	1,107
Cape Verdi-SAL Desalinization/Power	-	-	135	90
Sudan-Petroleum Training	-	200	-	-
Sahel Region-Accelerated Impact Programs	-	1,400	712	-
Djibouti-Energy Initiatives+	-	-	2,000	2,000
Africa Regional Projects	965	1,325	1,989	5,250
Program Development & Support	478	600	770	331
Improved Rural Technology	-	50	76	120
Accelerated Impact Program	487	675	1,143	1,530
Energy Initiatives for Africa	-	-	-	2,694
Environmental Training for Africans	-	-	-	575
TOTAL	6,000	12,127	14,035	13,609

* Excluding power generation projects.
\+ Financed from Economic Support Fund.

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Table 5

LATIN AMERICA AND CARIBBEAN ENERGY PROJECTS*

Country/Project Title	FY79	FY80	FY81	FY82 (estimate)
	($000s)			
Energy-related Forestry Projects	365	6,019	496	1,103
Costa Rica-Natural Resources Conservation	365	250	-	-
Ecuador-Fortry & Nat. Resources Conserv.	-	-	-	795
Haiti-Agroforestry Outreach	-	-	393	278
Honduras-Natural Resources Management	-	5,750	88	-
Peru-Reforestation Food for Work (SEPAS)	-	19	15	-
Peru-Expanded Reforestation (FFW)	-	-	-	30
Renewable Energy Projects	3,065	1,380	4,404	17,590
Ecuador-Alternative Energy Sources	-	-	1,100	1,300
Dom. Rep.-Energy Conserv. & Resources Dev.	-	-	-	12,672
Haiti-Appropriate Technology	-	100	-	-
Honduras-Rural Technologies	85	400	100	76
Jamaica-Integrated Rural Development	-	35	-	-
Panama-Alternative Energy Sources	450	25	50	-
Peru-Appropriate Rural Technology	80	-	-	-
Peru-Rural Enterprises II	100	-	-	-
Caribbean Reg.-Alternative Energy Systm	1,850	75	1,854	1,132
ROCAP-Fuelwood & Alt. Energy Sources	500	745	1,300	1,900
ROCAP-Reg. Industry Energy Efficiency	-	-	-	510
Other Energy Projects	2,525	350	12,938	5,333
Bolivia-Departmental Development Corp.	1,000	-	-	-
Costa Rica-Science & Technology	1,350	-	-	-
Costa Rica-Development Information	175	-	-	-
Dominican Republic-Energy Poliy Dev.	-	270	423	-
Jamaica-Program Development & Support	-	-	-	250
Jamaica-Energy Sector Assistance	-	-	3,000	4,500
Panama-Program Development & Support	-	25	8	13
Peru-Small Hydro Development	-	-	9,300	250
Caribbean Reg.-Program Dev. & Support	-	30	200	300
ROCAP-Program Development & Support	-	25	7	20
Latin America & Caribbean Reg. Projects	642	353	200	1,500
Science & Technology Info Transfer	50	-	-	300
Training & Development	-	50	-	800
Energy Resources Development	592	303	200	400
TOTAL	6,597	8,102	18,038	25,526

* Excludes power generation projects.

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Table 6

NEAR EAST ENERGY PROJECTS*

Country/Project Title	FY79	FY80	FY81	FY82 (estimate)
			($000s)	
Renewable Energy Projects	1,120	1,148	2,794	1,425
Morocco-Renewable Energy	-	600	1,494	1,425
Tunisia-Science & Technology Dev. I	120	-	-	-
Tunisia-Renewable Energy I	1,000	548	-	-
Tunisia-Renewable Energy II	-	-	1,300	-
Other Energy Projects	276	16,410	-	18,030
Egypt-Applied Science & Tech. Research+	276	60	-	-
Egypt-Tech. Transfer & Manpower Dev. I+	-	6,000	-	6,000
Egypt-Mineral, Petroleum & Groundwater+	-	10,350	-	-
Egypt-Utility Mgmt. & Energy Policy+	-	-	-	5,530
Egypt-#263012302+	-	-	-	6,500
Near East Regional Projects	553	70	-	130
Energy	400	-	-	-
Project Development & Support	153	70	-	130
TOTAL	1,949	17,628	2,794	19,585

* Excludes power generation projects.
\+ Financed from Economic Support Fund.

Table 7

BUREAU OF SCIENCE & TECHNOLOGY -- OFFICE OF ENERGY
ENERGY PROJECTS*

Project Title	FY79	FY80	($000s) FY81	FY82 (estimate)
Renewable Energy Projects	5,674	2,953	3,701	1,800
Low Cost Energy Technology	914	1,000	-	-
Low Cost Energy for Rural Poor	-	-	1,325	800
Bio-Energy Systems & Technology	1,510	200	-	1,000
Photovoltaic Technology	2,000	500	921	-
Renewable Energy Servey & Demonstration	250	600	1,052	-
Alternative Energy Training	1,000	645	403	-
Energy Efficiency & Conservation	-	8	-	-
Other Energy Projects	1,628	4,232	5,074	7,550
Energy Management Training	638	760	650	-
Energy Technical Service Support	-	500	400	300
Energy Policy & Planning Assistance	990	1,498	1,336	-
Decetralized Hydropower	-	1,224	1,000	800
Conventional Energy Assistance	-	500	400	300
Energy Policy Development & Conservation	-	-	-	1,00
Conventional Energy Training	-	-	2,521	2,000
TOTAL	7,302	7,185	8,775	9,350

* Excludes power generation projects.
\+ $500,000 finanaced by Economic Support Fund.

Table 8

BUREAU OF SCIENCE AND TECHNOLOGY -- ENERGY-RELATED PROJECTS

Project Title	FY79	FY80	($000s) FY81	FY82 (estimate)
Office of Forestry, Environment, and Natural Resources*				
Forestry Resources Managements	1,400	-	1,300	850
Agro Forestry	-	-	1,000	-
Forestry Sector Development	-	-	-	300
Subtotal	1,400	-	2,300	1,150
Office of Multisector Development*				
Alternative Rural Development Stratagies	-	4	6	14
Subtotal	-	4	6	14
TOTAL	1,400	4	2,306	1,164

*Excludes power generation projects.

Table 9

PROGRAM AND POLICY COORDINATION -- ENERGY-RELATED PROJECTS

Project Title	FY79	FY80	($000s FY81	FY82 (estimate)
Energy/Science & Technology Studies	-	-	51	200
TOTAL	-	-	51	200

for fuelwood and renewable energy projects. Fuelwood production and use has remained since the late seventies the highest priority for project development in the Africa Bureau's energy program. The Africa Bureau reports that its energy program for fuelwood and renewable energy projects more than tripled from approximately $3 million in FY 78 to $10 million in FY 81.[1] These figures conflict with those in Table 4, probably because the Africa Bureau classified more forestry projects as energy activities.

The programming of fuelwood and renwable energy projects by the Africa Bureau reflects a strong dichotomy between the projects for fuelwood production and for renewable energy per se. Only a few of the forestry and fuelwood projects try to explicity link production activities with end-uses. In these instances, the projects have a small component for testing and demonstrating improved wood stoves. Similarly, the renewable energy projects usually are not directly linked to fuelwood production.

Latin America and Caribbean Bureau

While the energy program of the Latin America and Caribbean Bureau has a large rural electrification component, renewable energy activities, especially fuelwood, are receiving increasing priority. The fuelwood and renewable energy activities are of four types. First, the Bureau is funding forestry and resource management projects. Second, it is financing species trials of fast-growing tree varieties for woodlots and energy plantations. Third, more efficient wood stoves, wood-burning kilns, and charcoal production technologies are being demonstrated. Also, solar drying of wood and bagasse prior to consumption is being tested in several countries. Finally, the Bureau is beginning to fund bio-conversion demonstrations that produce fuels that substitute directly for currently imported oil. These demonstrations of known technologies include: biomethanation of animal wastes to product gas for cooking and lighting, gasification of wood residues to fuel small electrical generation sets, utilization of coffee by-products to replace fuel oil used for drying, and wood-fired boilers to provide steam for electricity generation.

Similar to the criticism leveled at the energy program of the African Bureau, the Latin American Bureau's energy program can be criticized for the lack of linkage between fuelwood production and end-use in the project programming.

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1 Bureau for Africa, "Energy Forestry and Natural Resources Activities in the Africa Region," July 1982.

Near East Bureau

The renewable energy program of the Near East Bureau has been limited to a few projects, in Egypt, Morocco and Tunisia. In addition to energy planning assistance, the Bureau is funding demonstration projects of solar and wind technologies in Egypt and Tunisia as well as a demonstration of biogas technology in Egypt. In Morocco the Bureau initiated an energy development project which includes the establishment of a renewable energy center.

VII. FUELWOOD ENERGY ACTIVITIES OF OTHER DEVELOPMENT INSTITUTIONS

1. World Bank

The World Bank is currently involved in biomass energy in several ways. First, it makes loans for fuelwood and biomass energy projects as well as for other projects that have biomass energy components. Second, the Renewable Energy Division of the Bank's Energy Department is formulating a renewable energy program. This division has commissioned a number of studies on various renewable energy technologies and a summary report on these studies is under preparation. Third, in response to a request made at the 1980 Tokyo Summit of major aid donors, the World Bank is involved in "coordination" of aid efforts to "do more to help developing countries increase the use of renewable energy." The Bank plans to play a role in coordination through sector and energy planning missions, by identifying research and investment opportunities, and by assisting in project formulation.

At least three Bank projects presently contain components in which biomass wastes will be employed to generate electricity by first converting them to producer gas. In the Guyana Upper Demerara Forestry Project which was approved in 1979, the project plan included a 4500 kw power plant based on the gasification of wood residues. The plant will supply 2900 kw to the sawmill and the rest to the sawmilling complex and associated township. Two gasifier units, 75 kw and 145 kw, have been installed.

The second project is the Cameroon SEMRY II Rice Project (1978) which was envisioned to have a component where by-product rice husks would be gasified to produce electricity for the rice mill. The two pilot units that were tested in Cameroon did not perform as well as the wood-fueld Guyama gasifiers. The units have been withdrawn for further in-factory tests. The third project is the Mali Water/Power Project which was only recently approved. Again here the planned biomass energy component consists in the gasification of rice hulls to produce a total of 1950 kw of electric power.

A fourth producer gas activity is a study that the Bank is conducting with the aid of consultants. The study has a dual purpose: (1) to meet the Bank's operational need for guidelines in determining the general technical, economic and social context

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in which producer gas technology can be utilized in projects and (2) to determine whether there is a need for an organized, systematic global testing program on producer gas.

The above activities reflect the Bank's keen interest in helping developing countries maximize the contribution of their often abundant renewable energy resources to national energy needs. Since FY 78, the Bank has provided about $285 million of financing to some 25 countries for fuelwood planting in village woodlots, individual farms and large forest plantations. Most of the fuelwood production from such managed plantations as well as the residues produced from wood processing and agricultural activities are conceivably more econonically convereted to useful energy by producer gas equipment.

The lending program for energy projects by the Bank for the period FY 71-81 is shown in Table 10. It is seen that there has been increased support of renewable energy projects since 1976.

The World Bank is by far the lqrgest source of public support for energy development in developing countries-particularly for energy sources other than electic power. In some subsectors, the Bank is virtually the only agency providing both technical advice and financial assistance. While it is highly desirable that other agencies expand their efforts, the key role which the World Bank presently plays in the energy sector of developing countries and the very large investment requirements which lie ahead in those countries are the basis for a further expansion of the Bank's program in this sector.

The lending program projected for energy in FY 81-85 is shown in Table 11. It amounts to about US$13 billion or 17 percent of the Bank's total lending commitments planned for the five-year period. Based on a country-by-country review of investment needs and opportunities in the energy sector, it is felt by the Bank that a substantially larger program would be both feasible and desirable. The "desirable" program, also shown in the table, of US$25 billion, is US$12 billion larger than the planned program.

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TABLE 10

LENDING FOR RENEWABLE ENERGY
IN THE WORLD BANK'S ENERGY LENDING PROGRAM, FY71-81

(US$ millions)

	FY71-75 (Annual average)		FY76-80 (Annual average)		FY80 (Actual)		FY81 (Actual)	
	No. of Projects	Amount	No. of Projects	Amount	No. of Projects	Amount	No. of Projects	Amount
Oil and Gas	0.8	34.2	3.8	139.2	13	385.0	12	649.5
Electric Power (of which:)	13.6	524.2	20.4	1,358.8	25	2,392.3	17	1,323.0
Hydro	n.a.	n.a.	(6.4)	(341.6)	(10)	(783.0)	(7)[R]	(864.0)[R]
Geothermal	–	–	(1)	(9.0)	(1)	(40.0)	–	–
Coal and Lignite	–	–	0.4	16.4	1	72.0	1	10.0
Fuelwood[a/]	–	–	9.6[R]	43.8[R]	14	130.7[R]	8	28.0[R]
Alcohol	–	–	–	–	–	–	1	250.0
Industrial Retrofitting/ Refineries	–	–	–	–	1	29.0	1	110.0
Oil Shale	–	–	–	–	–	–	–	–
TOTAL ENERGY LENDING (of which)	14.4	558.4	34.2	1,558.2	54	3,009.0	40	2,370.5
RENEWABLES LENDING	n.a.	n.a.	17	394.4	25	953.7	16	1,142.0
RENEWABLES AS % OF TOTAL ENERGY LENDING	n.a.	n.a.	50	25	46	32	40	48

a/ Includes Forestry and other agriculture projects where fuelwood is a component.

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Table 11: CURRENT AND DESIRABLE WORLD BANK ENERGY LENDING PROGRAMS, FY 1981-85

(Million current US dollars)

	Current		Desirable	
	Lending Program	Total Project Cost	Lending Program	Total Projec Cost
Coal and Lignite /a	840	4,270	2,000	7,350
Oil and Gas				
Predevelopment	1,020	2,610	2,410	5,850
Oil Development /b	1,755	5,900	3,320	12,150
Gas Development /c	1,210	3,250	2,270	5,875
	3,985	11,760	8,000	23,875
Refineries	150	400	1,000	3,100
Renewables				
Fuelwood	425	850	1,100	2,200
Alcohol	200	2,100	650	4,550
	625	2,950	1,750	6,750
Electric Power	7,590	37,950	11,000	47,450
Industrial Retrofitting	0	0	1,250	3,825
TOTAL	13,190 /d	57,330	25,000 /d	92,350
Bank Share of Total Project Cost (percent)		23		27

/a Includes coal gasification projects.
/b Includes heavy oil projects.
/c Includes methanol.
/d Does not provide for any lending to China.

Note: On completion, the projects included in the Current Lending Program are estimated to produce (or in the case of electric power and industrial retrofitting projects, to save) energy equivalent to 1.62 million barrels of oil per day (mbdoe) or 5.3 percent of the developing countries' projected energy consumption in 1990. The corresponding estimates for the Desirable Lending Program are 2.9 mbdoe and 9.5%, respectively. Refineries, which add substantially to the value of petroleum products but not to energy output or savings, are excluded from the calculation.

Source: Energy in the Developing Countries, World Bank (August. 1982)

2. France

The French bilaterial aid program in energy is concentrated in French speaking countries. The renewable energy program in West Africa, much of which is in the Sahel, has comprised 69 projects, disbursing $22.8 million between 1976-79. Most of the projects have been in the solar field and use French made hardware. Early project emphasis was on solar thermal and solar photovoltic. Biomass technologies are still being researched in France and very few units are actually in the field test stage. These are two biomass projects. The first, in Upper Volta, is aimed at constructing anaerabic digesters out of local materials, and the second, located in Rwanda, is a study of biogas technology.

3. EEC: European Development Fund

The EEC has four division concerned with energy question: the Directorate General for Energy, the Directorate General for International Relations, the Directorate General for Science and Technology, and the Directorate General for Development Cooperatiion (the European Development Fund - EDF). Energy assistance programs are primarily the concern of EDF.

The program of the EDF is the result of a process of negotiation between the European Community and 53 assisted Atlantic, Caribbean and Pacific (ACP) countries. The first Lome Convention (1975-80) contained only three passing references to energy, but since 1978 the EEC Commission has acknowledged the need for an expanded energy program, including renewables.

In an aid package of 3,466 million EUA (European Units of Account), equal to US $4,329 million for 1975-80, the support of renewable energy projects as of May 1978 was only U.S. $3.42 million. The aid package for the 1980-85 period has been increased to $7.457 million, and with an increased attention to energy programs the allocations to renewable energy are expected to be increased substantially during the period

4. Germany

Germany has two organizations which provide foreign aid. The Kreditanstalt fur Wiederaufbau (KfW) is a capital aid agency which makes loans along the lines of the World Bank, while the Gesellscheft fur Technische Zusammenarbeit (GTZ) provides technical assistance and has a substantial staff working in developing countries. The overall coordinator is the Ministry of Economic Cooperation (BMZ).

Renewable energy program support from 1978 to 1979 was U.S. $48 million, out of a total energy budget of $2,094 million. Between 1976 and 1978 the BMZ implemented about 40 projects in water pumping, solar cooking, and other technologies which would be characterized as renewable energy projects. Past projects have included basic research and testing in biogas, gasification, pyrolysis, and ethanol production from biomass, as well as a host of non-biomass related activities such as solar thermal devices, windmills, and small scale hydro.

5. Sweden

The Swedish International Development Authority (SIDA) has an annual budget in excess of US $1 billion, and employs about 400 professionals in Stockholm and 80-100 in field offices. In the past, SIDA has concentrated 90% of its energy efforts to hydro projects, but since 1978 the primary interest and principal project activity in renewable energy has been in the forestry sector.

In the forestry sector Sweden is providing general purpose grants for forestry in several African countries. A plantation project of reforestation of 29,500 hectares in Mozambique is underway, with two nurseries producing more than a million seedlings per year. A social forestry project in India has a planting and nursery program utilizing new types of fast growing species. General assistance projects have included Ethiopia (1976-80), Lesotho (1980-85), Mozambique (1978-80), Tanzania (1976-82), and Bangladesh and Zambia (1980). Over US $13.4 million was disbursed through 1979 and another $48 million is planned to the year 1985.

6. Holland

The Dutch Aid Ministry concern with renewable energy sources dates from a 1977 Report "Difficulties Involved in Applying Solar Energy in Developing Countries", prepared by the Dutch Ministry of Foreign Affairs in collaboration with Philips.

Until 1980 Dutch renewable energy aid was concentrated on large solar refrigeration, as well as several individual projects in hydro, photovoltaic, solar thermal pumps and solar water heating and distillation. Total renewable energy aid excluding hydro through mid-1979 was US $6 million, with a commitment to provide $13 million for research through 1982, $50 million annually for afforestation programs, and dissemination of more efficient means of wood use. Special consideration is given to the Sahelian region of Africa.

The U.K. Overseas Development Administration (ODA) is in a particularly strong position to carry out projects that demand close host country planning and involvement, such as renewable energy programs, because Britain has through previous colonial organizations accumulated a quantity of data and expertise on natural resource conditions in many parts of the world which is probably unmatched by most other countries. Until 1978 the British aid program provided only a small percentage of budget allocation to renewable energy projects. However, a report in September 1978 entitled "Renewable Energy Sources for Developing Countries: An Initial Appraisal" focused official attention on technical research and development of small-scale, low cost energy schemes that would be appropriate for village level use. Following this report, several research and development projects are now being contracted to universities and research institutes in the U.K.

Since 1964 the Tropical Products Institute has conducted several research and development projects in the development of village-level biogas units. In addition, the production of charcoal has been investigated, as well as gasifiers for converting charcoal to motor power. The technologies have not been field tested on a wide scale, with research/development being about 2% of the energy program budgets and application/production being less than 1%.

8. Canada

The Candian International Development Agency (CIDA) is relatively young, being founded in 1968. CIDA has not funded renewable energy projects other than hydroelectric plants. The energy program is concentrated in three areas: 1) energy production, including hydro and thermal power stations; 2) energy resource evaluatior and 3) energy policy development.

TIME AND SHEAR DEPENDENT RHEOLOGY OF COAL WATER DISPERSIONS

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ABSTRACT

Rheology of thixotropic liquids is considered as a branch of science of great complexity. An attempt is made to explain and quantify thixotropic behavior of combustible coal water slurries (CWS). A testing procedure is recommended to isolate time dependent and shear dependent behavior of CWS and other thixotropic liquids. Experiments show considerable variation in values of apparent viscosities if time dependency of thixotropic liquids is not isolated.

The following basic model is proposed for quantification of thixotropic rheology.

$$\tau = f_1(t) + f_2(D)$$

Where τ is shear stress

t is shearing time

D is shear rate

For CWS the relationship is found to be

$$\tau = Ae^{-Bt} + \tau_0 + KD^n$$

Where A = Time consistency index

B = Time behavior index

τ_0 = Yield stress

K = Fluid consistency index

n = Fluid behavior index

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INTRODUCTION

The mechanics of liquid-solid suspensions is regarded as a branch of science of great complexity. Depending on the components involved, liquid-solid suspensions often exhibit flow behavior that is governed by a set of properties, which lead to entirely different responses than liquid or solid alone when subjected to stress or motion.

Rheology deals with the determination of a relationship involving deformation and flow of matter. The relationships between the rate of deformation (rate of shear) and corresponding development of shear stress are referred to as the rheological behavior (rheological property) of the fluid. From an engineering point of view, such behavior is of great importance.

RHEOLOGICAL CLASSIFICATION OF LIQUID-SOLIDS MIXTURES

Depending on the physical properties of the components involved, a liquid-fine solids particle mixture may exist in truly homogeneous form or appear in spurious homogeneity. If the suspended component involves relatively coarser solids particles, the power of the suspending component may not be strong enough to provide a uniform dispersion of the former throughout the fluid regime. Instead, higher solids concentration will be observed in its lower portion. A suspension left in such a manner is a heterogeneous one. But a typical CWS containing 70% by weight coal is observed to be a homogeneous suspension.

CLI formulated combustible CWS does not show any coal-water phase separation. Hence, we will limit our discussions to homogeneous CWS only. The rheological behavior of single phase suspensions can become rather complex. Such suspensions can be classified as shown in Figure 1.

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Typical shear stress and shear rate relationships for suspensions are shown in Figure 2 and Figure 3. Mathematical correlations for time independent rheology are discussed widely in literature, but fewer publications are available to correlate time dependent rheology. Combustible CWS containing 70% by weight of coal display time dependent rheology. CLI's proven CWS shows no yield, hence our discussions and data focus mainly on thixotropic - no yield rheology of coal-water mixtures.

TIME DEPENDENT BEHAVIOR OF COAL-WATER SLURRIES

Time dependent fluids have similar rheological properties to those of time independent fluids, except that their behavior is dependent on the duration of shear. If shear stress decreases with time at a given shear rate the fluid is called thixotropic. On the other hand, if a fluid behaves opposite to that of thixotropic, it is called rheopectic.

A typical CWS kept at rest for a reasonable time is likely to have irregular coal particles of different sizes closely linked by interparticle forces and added chemicals. Such linking gives a structured configuration to the slurry matrix. As a result of shear rate structural configuration and particle orientation changes resulting in different rheological behavior with time of shear. This is shown in Figure 4. It may be pointed out here that time dependency discussed in this paper relates to duration of shear rate and not the shelf life of a slurry. Thus, if we define apparent viscosity of a slurry as a ratio of shear stress to shear rate (τ/D), then thixotropic slurries show a decrease in apparent viscosity with time under constant shear rate. This behavior is sometimes termed as "shear thinning." Here the gel condition

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of slurry is transformed into a sol condition with shearing action. For large enough durations an equilibrium stress value is attained at that shear rate. The opposite of this is seen in rheopectic slurries and it is called "shear thickening."

Another important consideration which cannot be ignored when studying time dependent rheology is that pure thixotropic or pure rheopectic slurries regain their original structural configuration after a finite time called recovery period. Such a recovery period could vary depending on the fluid, from a few minutes to a few hours. Thus, pure thixotropic or pure rheopectic slurries show a reversible gel to sol or sol to gel transformation. In the case of irreversible transformation, the fluid does not regain its original structural configuration after shearing and there is a permanent change in the apparent viscosity of fluid. This behavior may be called rheodistruction. Some fluids may return only partially to original form. In such cases the amount of reversibility needs to be determined. In the case of CWS, rheopectic behavior is not as common as thixotropic behavior. Hence following discussion on measurement of rheological properties of CWS is limited to thixotropic slurries.

DETERMINING RHEOLOGY OF THIXOTROPIC SLURRIES

Coal-water slurries show thixotropic behavior as explained above. From an engineering point of view, it is important to know the rheology of a CWS including the time dependent effects. Judging the quality of CWS by knowing only an apparent viscosity measured at one shear rate without any knowledge of shear history could be misleading. Sometimes, not only this one point value of viscosity but also the well known "power

law" relationship between shear stress and shear rate could be erroneous for thixotropic slurries if the time duration and shear history of slurry for the test is not known. To illustrate this fact experimentally, several different tests were carried out on CWS and No. 6 fuel oil which exhibits thixotropy.

Measurements on thixotropic materials are almost invariably carried out on rotational viscometers so that shearing can be continued for as long as is desired. The sample is sheared between two concentric cylinders, one of which rotates. For the purpose of the present discussion, we may assume that the shear rate is proportional to the rate of rotation ("speed") of the rotating cylinder, and that the stress is proportional to the torque required to rotate the cylinder. Usually the shear rate is held constant for a period during which the shear stress decreases.

For this purpose a Haake RV-100 viscometer was used. Using this instrument shear rate can be linearly increased with time up to a predetermined value and then decreased to zero value. Thus a continuous increasing (up) and decreasing (down) curve for shear stress and shear rate can be obtained. Such a curve is called a rheogram.

Following is a brief description of the rheological tests performed on CWS and No. 6 fuel oil.

1. Fluids used - a. CLI's commercial CWS: 70% coal
   29% water
   1% additives

   b. No. 6 fuel oil

2. Three types of rheological tests were performed on the two fluids using different time durations for the test.

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Test Type A: These tests were more like conventional tests used for thixotropic fluids. During the test, shear rate is linearly increased within specific time period to a maximum value and then decreased to zero value at the same rate. Shear stress is measured during the test. For time dependent fluids such a test generates two different curves for shear stress vs. shear rate. As shown before, these curves generate a closed loop called "viscosity loop." "Power law" mathematical relationship between shear stress (τ) and shear rate (D) is determined for one of the curves, generally the ascending curve, to predict rheological behavior of the fluid.

But it is well known that the shape of the curve depends on the time duration of the test. During this experiment this type of test was carried out at 2 min., 4 min., 8 min., and 16 min. time duration on CWS and No. 6 fuel oil. It can be seen from the data displayed in Tables 1 through 4, that the power law coefficients and viscosity values at a particular shear rate vary to a great extent by changing the time duration. Figure 5 displays that the loop area significantly increases as the time duration of test increases.

Test Type B: This type of test is already being used for measurement of CWS rheology. This test consists of running a "viscosity loop" 3 times consecutively and determining rheological properties from the third ascending curve. It can be seen from Tables 5 through 8 that the powerlaw coefficients

do not show as much scatter but still sufficient variation can be seen. Figures 6 and 7 show different rheograms as the test time is changed. Here less variation with test time can be attributed to the slurry or oil being close to the equillibrium state at the third ascending curve.

Test Type C: This type of test consists of measuring shear stress at a constant shear rate with respect to time until the sample of slurry or oil comes to a steady state stress value. Then immediately running a viscosity loop up to a certain shear rate. This test was repeated by varying the viscosity loop duration from 2 min. to 16 min. as discussed before. It can be seen from Figure 8 that the viscosity loop run by this method does not show any loop area at all. This clearly indicates that the time dependency is terminated by previous shear treatment. Power law analysis on such a curve is reproducible and does not vary with the time duration of the test. Nonetheless, CWS shown to be displayed on highly pseudoplastic by Test Type A was revealed as less pseudoplastic in this test. This observation is evident from Tables 9 through 12. The author recommends this type of test for isolating time and shear rate dependent variables to evaluate thixotropic fluids.

MATHEMATICAL QUANTIFICATION

Not much literature is available for quantifying rheology of time dependent fluids. Generally, by fixing the testing time, all the time dependent variables are assumed to influence in same way and then only stress vs. shear rate relationship is reported. Such a relationship could be non-reproducible depending upon sample handling or other shear

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history. From the previous discussion it is clear that time dependency can be completely isolated by imparting shear for enough time so that the fluid comes to an equilibrium state. This behavior of thixotropic slurry and oil indicates that shear stress is an independent function of time and shear rate. Therefore, the following basic model is assumed.

$\tau = f_1(t) + f_2(D)$.....1

such that, as $t \rightarrow \infty$, $f_1(t) \rightarrow 0$ for $D > o$

Proposed form of $f_1(t)$ is

$f_1(t) = Ae^{-Bt}$, where t is the shearing time.....2

$f_2(D)$ is a function of shear rate only which may be of the form as

$f_2(D) = \tau_0 + KD^n$.....3

Where τ_0 = yield stress

k = fluid consistency index

n = fluid behavior index

For only shear rate dependent fluids Eq. 3 reduces to the modified power law model.

Hence complete form of Eq. 1 becomes

$\tau = Ae^{-Bt} + \tau_0 + KD^n$.....4

In the experiments conducted on CWS and No. 6 fuel oil no significant values of τ_0 were observed so in the present discussion we will drop yield stress term thus our model becomes

$\tau = Ae^{-Bt} + KD^n$.....5

Sometimes for a highly thixotropic slurry a large value of A in Eq. 5 could give a false impression of the yield stress value. if time dependency is not isolated.

For Test Type C discussed before it is easy to determine coefficients in Eq. 5. In the first part of the test τ is measured by keeping D constant and varying t, thus giving values of A and B. Then in the second part the slurry is at equilibrium so $f_1(t) = o$, hence values of k and n can be determined by measuring τ with D at equilibrium.

The numerical value of A gives the degree of structure formation in the slurry at rest, while that of B indicates shear thinning characteristics. Negative values of B shows shear thickening phenomena. K and n have the same interpretations as powerlaw coefficients.

REMARKS

Test Type C appears to be an effective way of characterizing thixotropic fluids, especially coal-water mixtures. Test time dependency cannot be ignored to understand rheology of CWM. CoaLiquid's proprietary specifications on A, B, k and n have helped our engineers to deal with complexities involved in CWM rheology.

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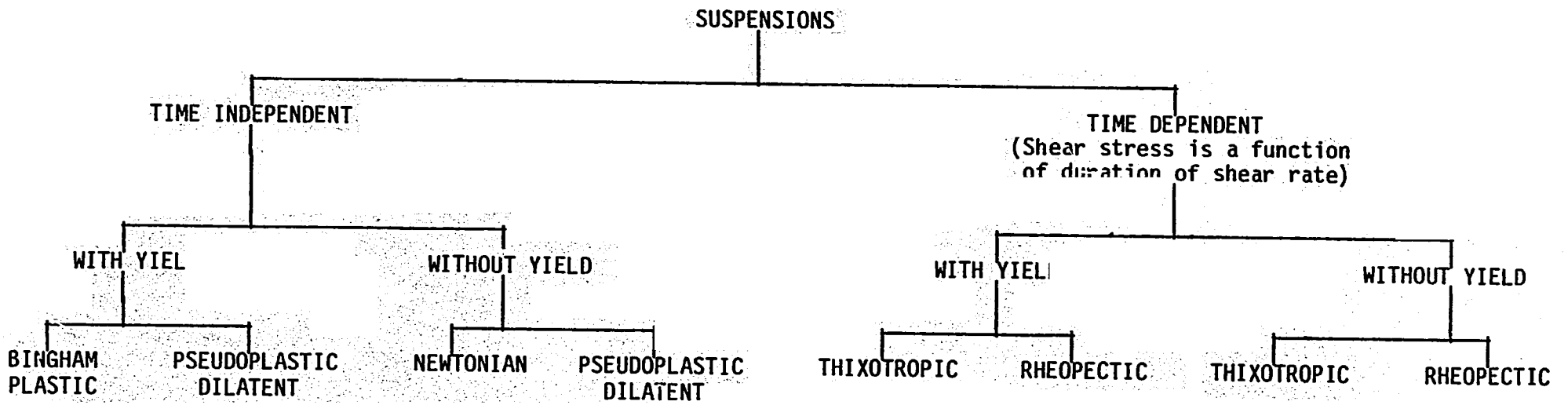


FIGURE 1 - RHEOLOGICAL CLASSIFICATION OF SUSPENSIONS

FIGURE 2

TIME INDEPENDENT FLUIDS

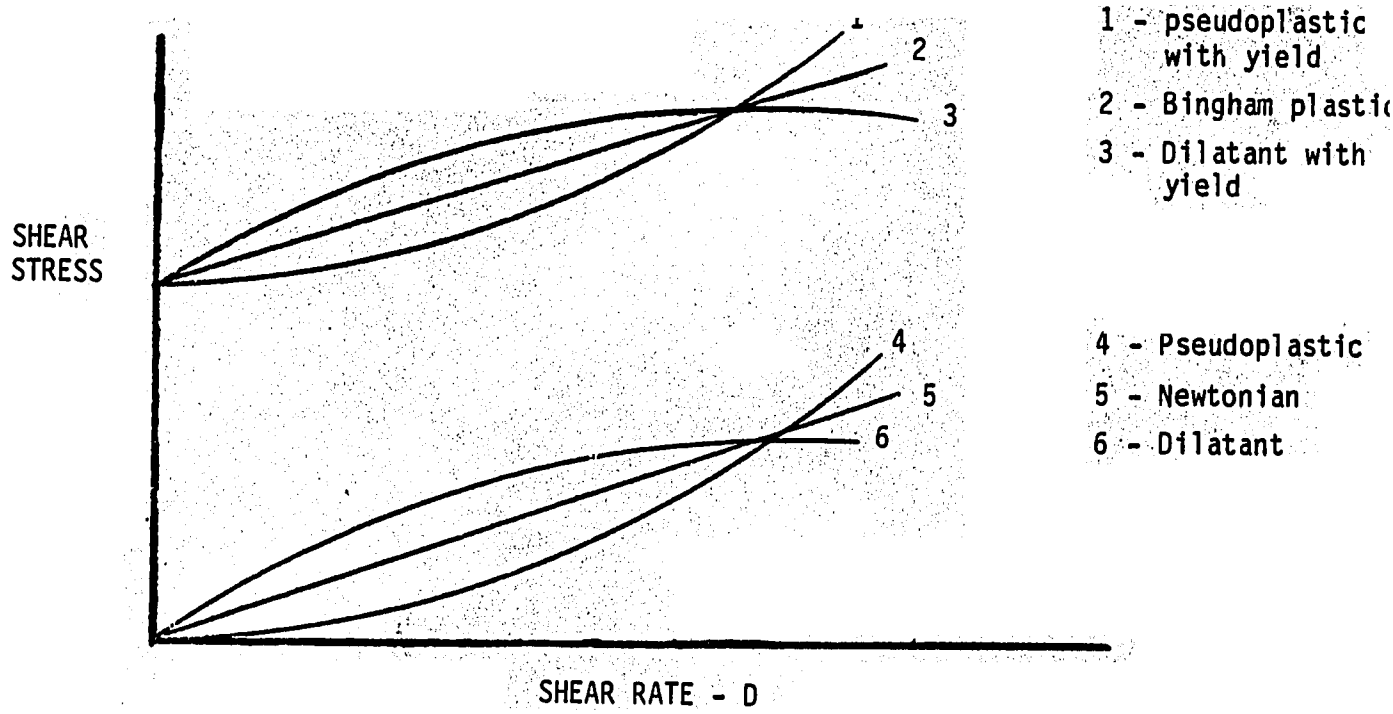


FIGURE 3

TIME DEPENDENT FLUIDS

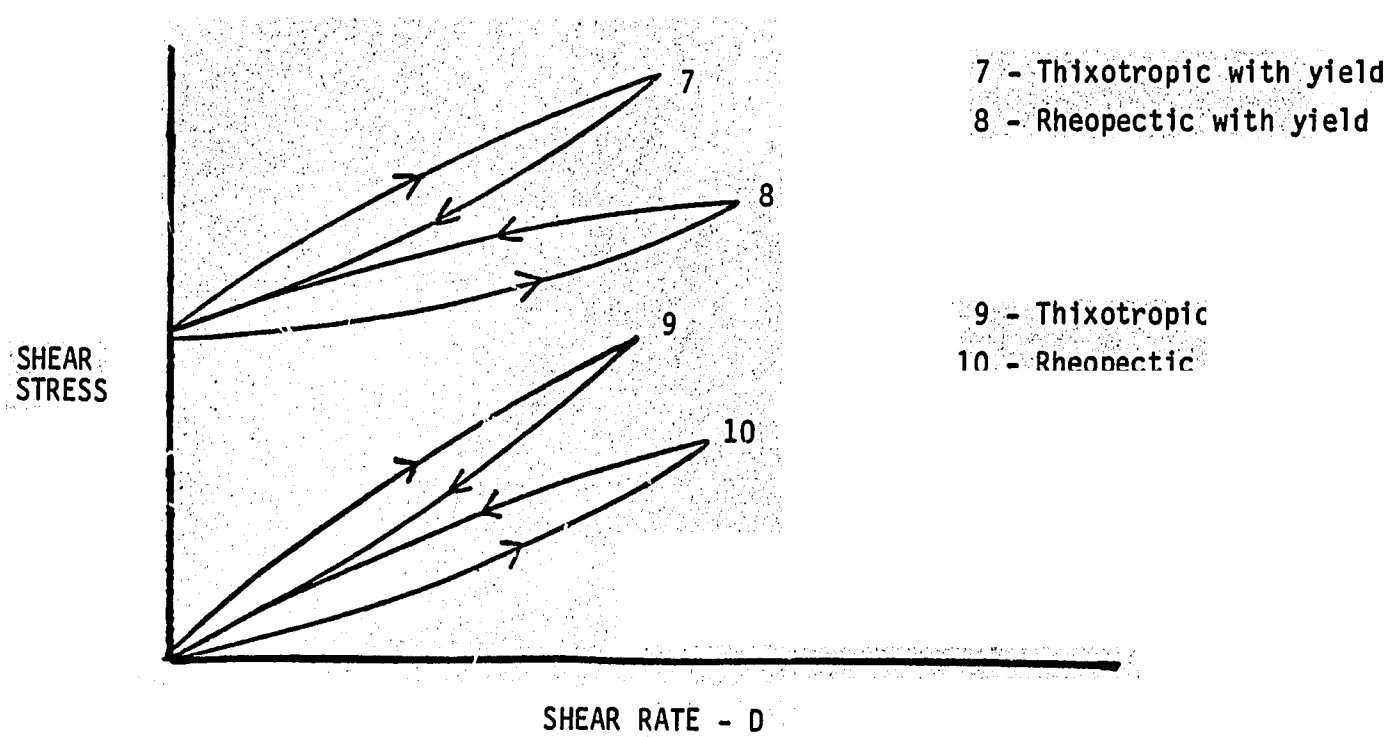
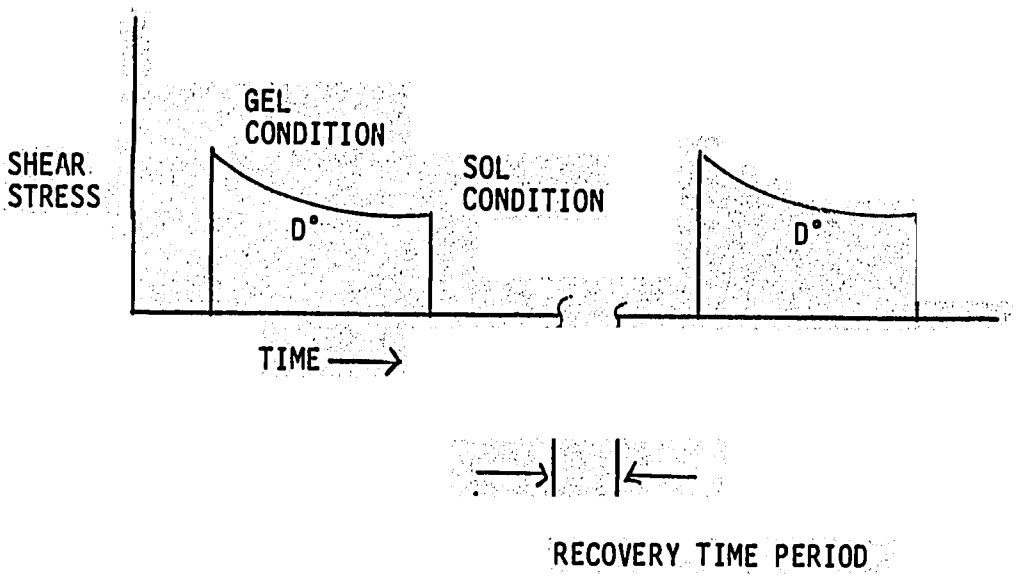
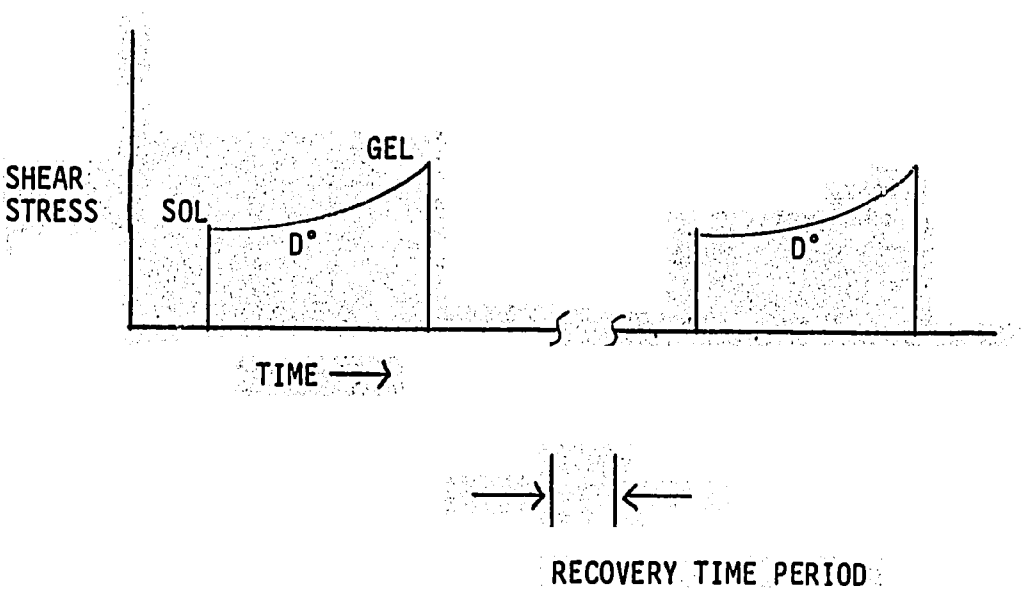


FIGURE 4

TIME DEPENDENCY OF SHEAR STRESS



a. THIXOTROPIC SLURRY



b. RHEOPECTIC SLURRY

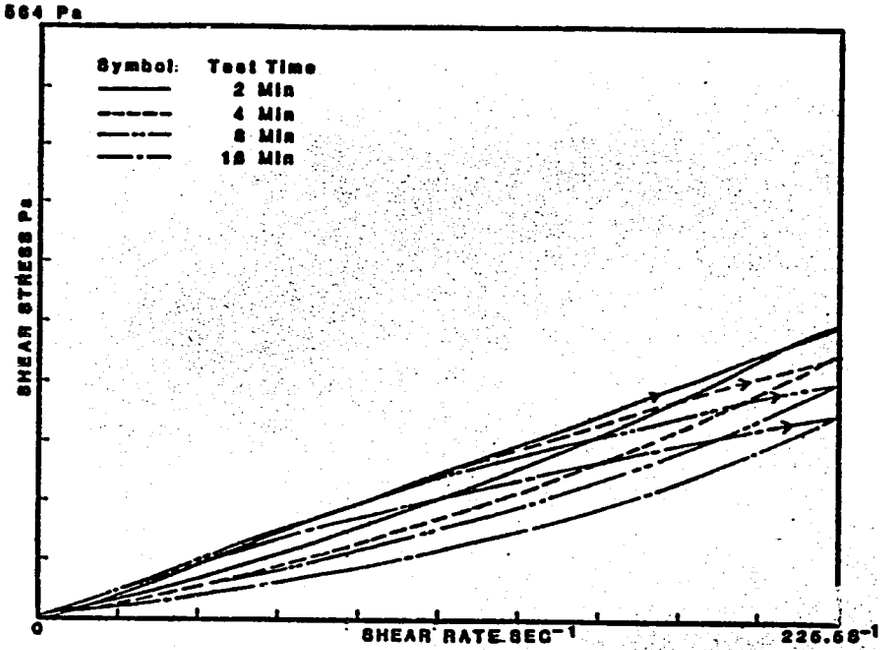


Figure-5 CWS RHEOGRAMS AT DIFFERENT TEST TIME INTERVALS.

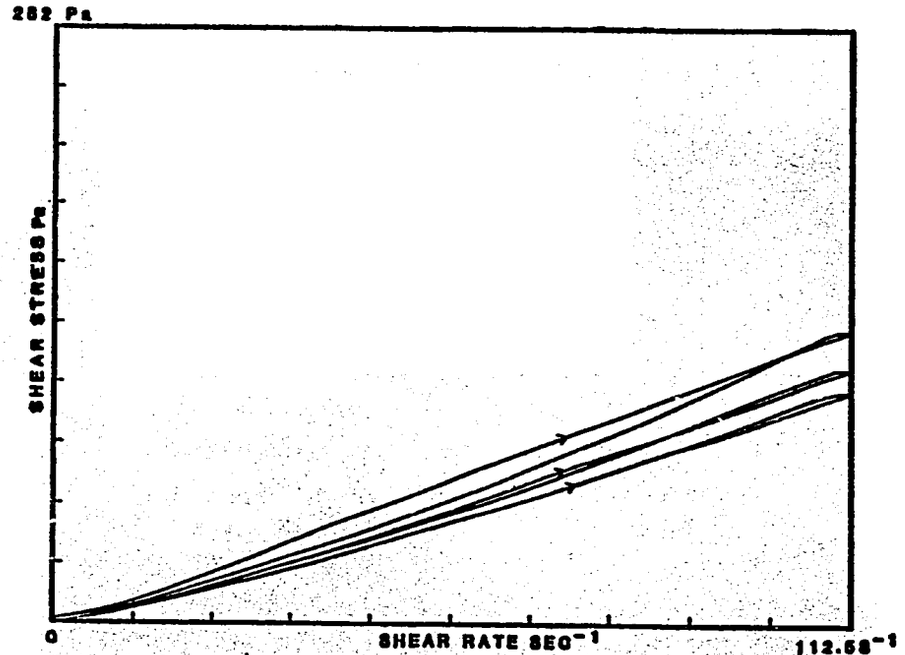


Figure-6 CWS RHEOGRAM USING TEST TYPE B AT 2 MIN LOOP TIME

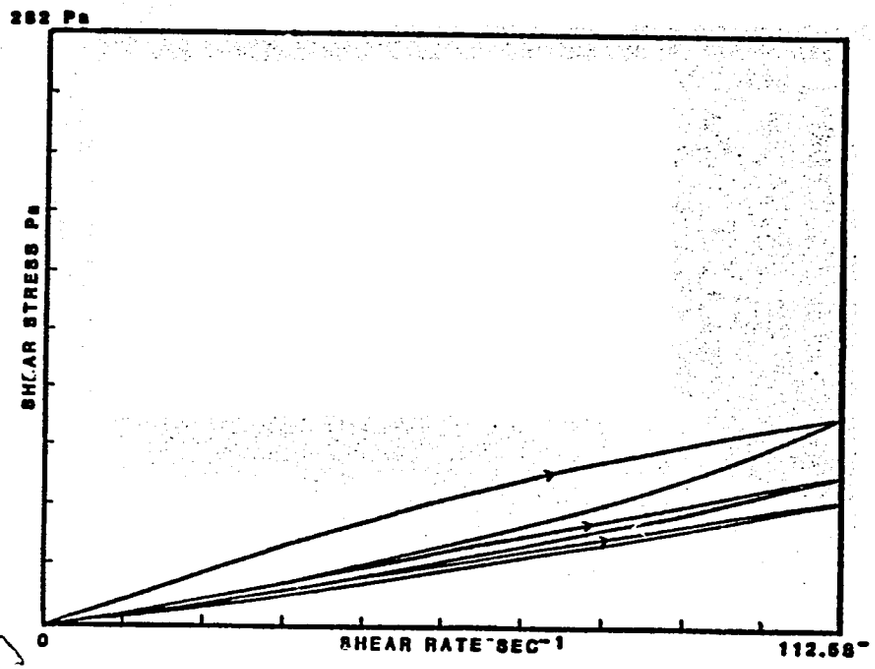


Figure-7 CWS RHEOGRAM USING TEST TYPE B AT 16 MIN LOOP TIME

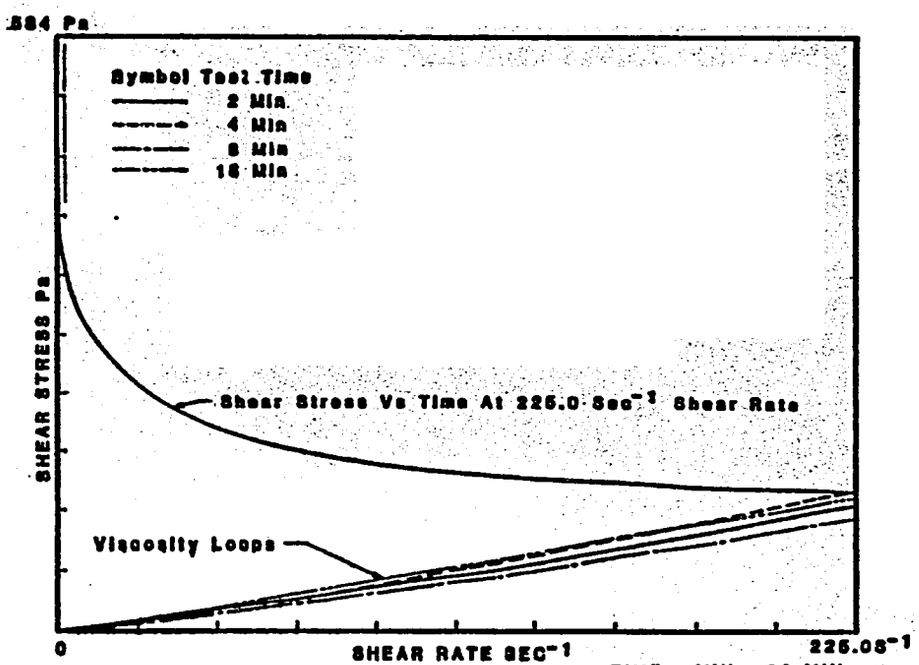


Figure-8 RHEOGRAM OF CWS BY TEST TYPE C TIME MIN 20 MIN

SHEAR RATE (sec^{-1})	VISCOSITY (cps) CMS	VISCOSITY (cps) #6 OIL
22.55	1000.4	2000.9
45.10	1150.5	1975.9
67.65	1208.9	2000.9
90.20	1250.5	2000.9
112.75	1219.3	2000.9
135.30	1225.5	1959.2
157.85	1229.7	1929.4
180.40	1232.7	1907.1
202.95	1234.9	1889.7
225.50	1231.1	1875.8
Power Law Coefficients	R^2 = 0.99 K = 1.10 N = 1.00	R^2 = 1.00 K = 2.21 N = 0.97

TABLE 1 - VISCOSITY VALUES FOR 2 MINUTE LOOP FOR TEST TYPE A

SHEAR RATE (sec^{-1})	VISCOSITY (cps) CMS	VISCOSITY (cps) #6 OIL
22.55	1000.4	5002.2
45.10	1163.0	5002.2
67.65	1208.9	4835.5
90.20	1219.3	4689.6
112.75	1225.5	4552.0
135.30	1208.9	4443.6
157.85	1179.1	4344.8
180.40	1156.8	4220.6
202.95	1139.4	4140.7
225.50	1113.0	4051.8
Power Law Coefficients	R^2 = 0.99 K = 1.04 N = 0.98	R^2 = 1.00 K = 7.12 N = 0.90

TABLE 2 - VISCOSITY VALUES FOR 4 MINUTE LOOP FOR TEST TYPE A

SHEAR RATE (sec^{-1})	VISCOSITY (cps) CMS	VISCOSITY (cps) #6 OIL
22.55	1125.5	4752.1
45.10	1250.5	4376.9
67.65	1242.2	4218.5
90.20	1219.3	4126.8
112.75	1185.5	4001.8
135.30	1125.5	3918.4
157.85	1107.6	3823.1
180.40	1063.0	3751.7
202.95	1146.3	3696.1
225.50	1033.8	3601.6
Power Law Coefficients	R^2 = 0.96 K = 1.91 N = 0.88	R^2 = 1.00 K = 6.85 N = 0.88

TABLE 3 - VISCOSITY VALUES FOR 8 MINUTE LOOP FOR TEST TYPE A

SHEAR RATE (sec^{-1})	VISCOSITY (cps) CMS	SCOSITY (cps) #6 OIL
22.55	1125.5	4251.9
45.10	1138.0	4126.8
67.65	1117.2	4001.8
90.20	1063.0	3876.7
112.75	1025.4	3801.7
135.30	958.8	3668.3
157.85	929.0	3930.3
180.40	922.3	3520.3
202.95	889.3	3462.6
225.50	862.9	3351.5
Power Law Coefficients	R^2 = 1.00 K = 1.81 N = 0.85	R^2 = 1.00 K = 5.90 N = 0.85

TABLE 4 - VISCOSITY VALUES FOR 16 MINUTE LOOP FOR TEST TYPE A

SHEAR RATE (sec^{-1})	VISCOSITY (cps) CMS	VISCOSITY (cps) #6 OIL
11.28	750.3	4001.8
22.55	687.8	4001.8
33.83	750.3	4001.8
45.10	812.9	4001.8
56.38	850.4	4001.8
67.65	875.4	4001.8
78.93	893.2	4001.8
90.20	922.3	4001.8
101.48	944.9	4112.9
112.75	962.9	3901.7
POWER LAW COEFFICIENTS	R^2 = 1.00 K = 0.49 N = 1.14	R^2 = 1.00 K = 4.00 N = 1.00

TABLE 5 - VISCOSITY VALUES FOR 2 MINUTE LOOP FOR TEST TYPE B

SHEAR RATE (sec^{-1})	VISCOSITY (cps) CMS	VISCOSITY (cps) #6 OIL
11.28	625.3	4001.8
22.55	562.7	4151.8
33.83	625.3	4168.5
45.10	625.3	4126.8
56.38	665.3	4101.8
67.65	679.5	4035.1
78.93	696.7	4001.8
90.20	703.4	4001.8
101.48	722.5	4001.8
112.75	725.3	3901.7
POWER LAW COEFFICIENTS	R^2 = 1.00 K = 0.46 N = 1.09	R^2 = 1.00 K = 4.27 N = 0.99

TABLE 6 - VISCOSITY VALUES FOR 4 MINUTE LOOP FOR TEST TYPE B

SHEAR RATE (sec^{-1})	VISCOSITY (cps) CMS	VISCOSITY (cps) #6 OIL
11.28	625.3	4001.8
22.55	562.7	4001.8
33.83	541.9	4001.8
45.10	562.7	4001.8
56.38	600.3	3801.7
67.65	583.6	3835.0
78.93	607.4	3858.8
90.20	603.4	3876.7
101.48	611.4	3779.4
112.75	625.3	3701.6
POWER LAW COEFFICIENTS	R^2 = 1.00 K = 0.55 N = 1.02	R^2 = 1.00 K = 4.15 N = 0.98

TABLE 7 - VISCOSITY VALUES FOR 8 MINUTE LOOP FOR TEST TYPE B

SHEAR RATE (sec^{-1})	VISCOSITY (cps) CMS	VISCOSITY (cps) #6 OIL
11.28	375.2	3001.3
22.55	437.7	3501.5
33.83	458.5	3668.3
45.10	469.0	3751.7
56.38	490.2	3801.7
67.65	500.2	3668.3
78.93	507.4	3715.9
90.20	509.6	3626.6
101.48	516.9	3668.3
112.75	525.2	3631.6
POWER LAW COEFFICIENTS	R^2 = 1.00 K = 0.38 N = 1.00	R^2 = 1.00 K = 3.74 N = 0.98

TABLE 8 - VISCOSITY VALUES FOR 16 MINUTE LOOP FOR TEST TYPE B

SHEAR RATE (sec^{-1})	VISCOSITY (cps) CMS	VISCOSITY (cps) #6 OIL
22.55	500.2	2751.2
45.10	500.2	3001.3
67.65	458.5	3084.7
90.20	469.0	3188.9
112.75	500.2	3201.4
135.30	504.4	3251.4
157.85	518.1	3215.7
180.40	531.5	3251.4
202.95	536.3	3223.6
225.50	547.7	3201.4
POWER LAW COEFFICIENTS	R^2 = 1.00 K = 0.41 N = 1.04	R^2 = 1.00 K = 2.31 N = 1.07

TABLE 9 - VISCOSITY VALUES FOR 2 MINUTE LOOP FOR TEST TYPE C

SHEAR RATE (sec^{-1})	VISCOSITY (cps) CMS	VISCOSITY (cps) #6 OIL
22.55	375.2	3251.4
45.10	375.2	3251.4
67.65	375.2	3334.8
90.20	393.2	3376.5
112.75	400.2	3401.5
135.30	416.8	3326.5
157.85	428.6	3372.9
180.40	437.7	3345.2
202.95	458.5	3334.8
225.50	470.2	3276.4
POWER LAW COEFFICIENTS	R^2 = 1.00 K = 0.40 N = 1.02	R^2 = 1.00 K = 3.19 N = 1.01

TABLE 10 - VISCOSITY VALUES FOR 4 MINUTE LOOP FOR TEST TYPE C

SHEAR RATE (sec^{-1})	VISCOSITY (cps) CMS	VISCOSITY (cps) #6 OIL
22.55	500.2	3751.7
45.10	437.7	3251.4
67.65	458.5	3334.8
90.20	450.2	3376.5
112.75	450.2	3401.5
135.30	458.5	3334.8
157.85	475.2	3344.8
180.40	500.2	3314.0
202.95	516.9	3279.2
225.50	525.2	3226.4
POWER LAW COEFFICIENTS	R^2 = 0.99 K = 0.41 N = 1.02	R^2 = 1.00 K = 3.20 N = 1.02

TABLE 11 - VISCOSITY VALUES FOR 8 MINUTE LOOP FOR TEST TYPE C

SHEAR RATE (sec^{-1})	VISCOSITY (cps) CMS	VISCOSITY (cps) #6 OIL
22.55	500.2	3251.4
45.10	500.2	3376.5
67.65	500.2	3501.5
90.20	500.2	3501.5
112.75	500.2	3501.5
135.30	500.2	3501.5
157.85	535.9	3501.5
180.40	562.7	3439.0
202.95	583.6	3418.2
225.50	587.8	3351.5
POWER LAW COEFFICIENTS	R^2 = 1.00 K = 0.38 N = 1.03	R^2 = 1.00 K = 3.18 N = 1.02

TABLE 12 - VISCOSITY VALUES FOR 16 MINUTE LOOP FOR TEST TYPE C