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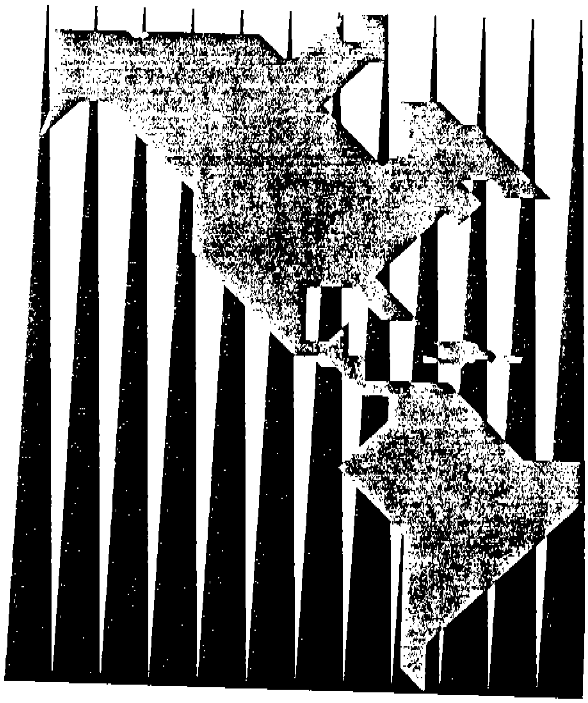

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ABLATIVE FAST PYROLYSIS: CONVERTING WOOD, AGRICULTURAL WASTES AND CROPS INTO ENERGY AND CHEMICALS

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Abstract

Each year more than 170 million tonnes (190 million tons) of yard waste, pallets, forest and agricultural residues are discarded that could become feedstocks for saleable products. The United States could potentially grow more than 450 million tonnes (500 million tons) per year of energy crops as dedicated feedstocks in an economically and environmentally sustainable way. About 85% of this lignocellulosic material can be converted into a biocrude oil and charcoal via fast pyrolysis. An engineering scale pyrolysis system has been designed and is being built according to the NREL ablative vortex fast pyrolysis concept in Kansas City. The system has been designed for a throughput of 32.7 dry tonnes (36 dry tons) per day (TPD) of biomass. The 13 mm (1/2") particles enter the vortex reactor where the solid biomass is heated very quickly and is converted into oil vapors, gas, char, and water. The char particles are separated from the hot gas and vapor stream. Next, the vapors are condensed to form an oil that is removed for sale or for upgraded products. The residual non-condensible gases are then sent back to the furnace where they are burned to provide process heat. The 36 TPD unit is projected to cost $1.5 million to build. This scale is appropriate for waste feedstocks that are available with a tipping fee in selected locations in the United States. Larger scale units of 90 tonnes (100 tons) and 227 tonnes (250 tons) per day are being designed to gain economies of scale in larger operations. The environmental impacts of a properly designed fast pyrolysis system are minimal and continue to be monitored at all these scales. Fast pyrolysis offers an excellent process for converting biomass into oils, char, and chemicals, much like a petroleum refinery does for crude oil.

Fast Pyrolysis

Fast pyrolysis is a process that converts biomass into a biocrude oil, with yields up to 70% by weight (wet). This material can be used without upgrading as a No. 6 fuel oil replacement or as a feedstock for producing chemicals and polymers. A second product is charcoal, with about a 15% yield that can be sold as a product or used as fuel for the process. The remaining 15% is a non-condensible, medium heating value (medium Btu) gas that is burned to provide process heat.

Fundamental and applied research and engineering development over the past 13 years has demonstrated that continuous reactors can be used with very fast heating rates and short residence times to produce high yields of liquids from biomass. Several reactor types are being explored around the world to provide the operating conditions necessary to obtain optimum liquid yields. Examples of configurations are ablative vortex, cyclonic, entrained flow, and fluidized bed. Each reactor provides the necessary controlled conditions of rapid heat transfer to the biomass, coupled with short biomass particle residence times and rapid quench of the gases. The National Renewable Energy Laboratory (NREL) developed the ablative pyrolysis system that is based on the vortex reactor concept, and is transferring the technology to Energy Conversions, a subsidiary of Interchem Environmental, for commercialization.

Ablative fast pyrolysis occurs in a vortex tube. Heat is transferred by contacting the biomass with the hot reactor wall with no oxygen present. The particles rapidly slide along the hot (approximately 500° - 600°C [1100° - 1200°F]) reactor wall and the biomass particle outer surfaces are vaporized, while the unconverted internal material remains relatively cool. The product is a mixture of non-condensible gases, water vapor, and pyrolysis vapors composed of polymer fragments from the original biomass. The wall temperature is achieved by burning the non-condensible gases supplemented, if necessary, by natural gas or char in a furnace surrounding the reactor tube. The residence time of the gases in the reactor is about one second to minimize the time the pyrolysis vapors are exposed to the high temperatures. This prevents secondary reactions from occurring that seriously impact the quality of the produced oil. The particles are recycled until they are so small that they are re-entrained in the exiting pyrolysis vapors. After leaving the reactor, the char particles are separated from the hot gas and vapor stream. Next, the vapors are condensed to form a biocrude oil. The remaining non-condensible gases are sent to the furnace where they are burned to provide process heat.

Interchem through Energy Conversions is scaling-up the ablative fast pyrolysis process, and expects to commercialize the pyrolysis of biomass into biocrude oil and charcoal within one year. A first generation prototype plant (commercial scale - 32.7 dry tonnes [36 dry tons] per day) has been built and tested using an Interchem pyrolysis design (Johnson et al. 1993). A second generation of the vortex reactor of the same size is currently being completed and the system is being set up based on the NREL pyrolysis design and the experience gained during the operation of the first generation plant.

Process Description for the Scale-up Reactor at Kansas City

The fast pyrolysis demonstration facility contains several major subsystems. The overall process and equipment for the scale-up facility are outlined below. The overall layout of the unit is shown in Figure 1 and a flow diagram of the process is shown in Figure 2. Only the reactor and furnace represent new technology; the remainder of the process is found in use in other industries and was partially tested in the first generation prototype.

Wood Handling Sub-system - Dry wood (13 mm [1/2"]) is delivered by live bottom storage trucks and is transported within the plant by conveyors and bucket elevators. The wood will have been dried and sized at another location.

Vortex Reactor Pyrolysis Sub-system - The wood enters the 1.2 tonne (1.5 tons) capacity hopper. The bottom of the hopper has a vibratory screen that delivers the wood to the feeder system. The wood is discharged into the eductor through a rotary valve that serves as a pressure seal. The eductor uses recycled pyrolysis gases from the pyrolysis system to pneumatically transport the wood particles to the vortex tube for reaction.

The vortex reactor is enclosed in a furnace that is designed to burn the medium Btu reactor gas and natural gas. The natural gas is used for starting the system and as a supplemental fuel source during steady state operation, if required. The medium Btu gas enters the furnace after the condensible oil vapors have been removed in the condensing system.

Separation Sub-system—It is composed of the following:

Cyclone - The vapor rich gases leave the vortex reactor along with the char particles that are entrained in the gas stream. This mixture then enters a cyclone designed to remove 99.5% of the char from the gas stream. The char then enters the char handling system and the gases go to the condenser.

Condenser - The gases from the pyrolysis unit enter the condenser at process temperature and are cooled to approximately 13-15°C (~55 °F) via a multiple stage condenser system. The vapors are condensed to liquid oil and returned to the sump. Approximately 11 liters (three gallons) of oil per minute are discharged to the storage tanks.

Oil Handling - The oil is pumped to one of three 19,000 liters (5,000 gallon) storage tanks. These tanks are surrounded by a drainage system on a sloping floor and are covered by a roof. When the tankers are loaded, the truck will be backed into the diked area so that any potential spill is contained.

Char Handling - The char is cooled and conveyed with a water jacketed screw conveyor from the cyclone into a covered storage silo. This is done in a nitrogen atmosphere to avoid char degradation.

Fast Pyrolysis Product Markets

The fast pyrolysis process that produces a pyrolytic oil or a biocrude appears to be one of the more promising techniques for producing fuels, electricity, and chemicals in the near and medium term for biomass and related wastes. For energy use, one of the advantages of biocrude oil is that it has about four times the volumetric energy density relative to the starting biomass feedstock, and is a storable liquid that can be transportable by dedicated pipeline or tanker to end users. The European Community RD&D program has several major projects underway for biocrude use as a fuel for boilers and gas turbines, as a refinery feedstock for manufacturing a petroleum extender, and as liquid fuel for diesel engines through direct hydrogenation (Bridgwater and Grassi 1992). The char co-product can be used as an on-site fuel or alternatively used as charcoal or converted to activated charcoal for pollution control applications. The potential pathways are shown in Figure 3.

Char and Charcoal

In the United States, the charcoal briquetting industry has grown from 450 kt (490,000 tons) in 1970 to 620 kt (690,000 tons) [1 kt = 1,000 tonnes] in 1987 with a retail sales value of $434 million. As a result of the Clean Air Act Amendments of 1990, many of the existing charcoal production facilities are closing because of the difficulty of making the existing kiln processes meet the more stringent requirements. We expect the fast pyrolysis processes to meet the necessary requirements. It is forecast that producing char for both charcoal briquettes and activated charcoal using fast pyrolysis will increase significantly. The activated charcoal market is growing rapidly as secondary water treatment becomes commonplace and the present market of 350 kt (382,000 tons) is anticipated to grow at a rate of 4-5% y^{-1} due to air and water treatment regulations being adopted worldwide.

Biocrude Oil for Thermal Uses

The oils produced by the process are oxygenated fuels that have an gross energy content of about 25 MJ l^{-1} (90,000 - 95,000 Btu/gal) or one half that of No. 6 fuel oil on a volumetric basis. The biocrude oil can be used as a replacement for No. 6 fuel oil. One of the primary advantages of wood pyrolysis fuel oil over No. 6 fuel oil is that it contains little sulfur. Under the regulations being implemented for the Clean Air Act, sulfur oxide (SO_x) air emissions are being increasingly tightly regulated. Promising research in Finland is exploring the use of biocrude oil to fuel large stationary diesel engines for electricity production (Guste 1993).

The boiler and turbine fuels market is the largest possible application and the lowest value use of the biocrude. The advantages of the higher energy density and the liquid form are such that it is possible to use it as a fuel in large central thermal facilities that have inherently high efficiencies, and its production can be decentralized and close to the source of biomass and residues. Also by storing the biocrude and using it in a gas turbine, it can be used for peaking and intermediate load applications in the utility sector (Overend and Bain 1992).

Transportation Fuels

The other energy market for fast pyrolysis derived material is in the transportation sector. In the United States, extensive research is being carried out using fast pyrolysis vapors as a feedstock for a cracking process to produce an olefin stream that will be used in synthesizing mixed oxygenates used in gasoline (Overend, 1991; Rejai et al. 1991). The olefin stream is produced over a catalyst that will convert the pyrolysis vapors into a mixed olefin stream with a relatively low concentration of aromatics. This stream is then catalytically reacted with an alcohol such as methanol or ethanol to produce mixed ethers similar in properties to methyl tertiary butyl ether (MTBE) and ethyl tertiary butyl ether (ETBE) that are produced commercially by combining isobutylene with the alcohols. MTBE is added to the gasoline pool to increase the octane value of the base gasoline and to increase the oxygen content of the fuel to the levels required for non-attainment air quality zones under the air quality rules for 1993 (Diebold et al. 1992).

Alternative strategies for transportation fuels are being followed in both Europe, where traditional Ni/Mo and Co/Mo hydrotreating catalysts are being used (Laurent et al. 1992), and in Canada where hydrogenation of biocrudes is being investigated over zeolite catalysts using hydrogen donor solvents (Sharma and Bakhshi 1992).

Chemicals, Adhesives and Polymers

In addition to using the oil as a fuel, there are numerous chemicals that can be fractionated or produced from the biocrude oil. The chemicals examined to date include a phenol replacement in phenolic resins and other extractable materials such as hydroxyacetaldehyde, levoglucosan, calcium acetate and calcium formate. Other products from catalytic upgrading include butadiene, pentanes, benzene, toluene and xylene (BTX) (Elliott et al. 1991). An overview of the pathways for upgrading biocrude can be found in Figure 3.

Interchem is a member of the Pyrolysis Materials Research Consortium (PMRC) as are Allied-Signal Corporation, Aristech Chemical Corporation, Plastic Engineering Company and MRI Ventures, Inc., the managing company (Chum and Power 1991). The consortium collaborates with the U.S. DOE Office of Waste Reduction in a cost shared program with NREL. This collaborative is developing applications for a phenolic-rich extract made from biocrude oil to replace petroleum derived phenol in phenol-formaldehyde thermoset resins (Chum et al. 1989, Chum and Black 1990).

There are numerous products that result from fast pyrolysis in addition to phenolics. One can view the fast pyrolysis as the primary step in a biomass refinery that, like a petroleum refinery, would have a fuels output and a chemicals product stream as shown in Figure 3. Also, there is the possibility of specialty products such as flavor compounds for foodstuffs that are presently produced by Red Arrow using a fast pyrolysis process (Underwood and Graham 1991).

Producing chemicals from fast pyrolysis is also being developed through two other markets: road deicers and a polymer precursor (levoglucosan). These chemical products are being investigated in Canada and elsewhere (Oehr and Barrass 1992). The yield of levoglucosan can be controlled so that it can be obtained in high yield if the cellulosic component of the feedstock is pretreated to remove ionic contaminants. This changes the pyrolysis pathway from one that produces hydroxyacetaldehyde as the predominant cellulose derived product to levoglucosan in greater than 30% yield on cellulose (Longley et al. 1992).

Carbon Blacks

Commercial carbon blacks are in considerable demand worldwide as a rubber reinforcing agent. The largest single market for carbon blacks is the automobile industry (about 50% of the weight of a tire is carbon black). Carbon blacks are also used in industrial rubber products and specialty plastics, and in pigments for inks and toners for copy machines. Specifications for carbon blacks are very demanding and it will be difficult to penetrate this market.

The world market in 1988 exceeded 4 Mt (4.5 million tons) [1 Mt = 10^6 tonnes] of carbon blacks with the largest consumer being the United States (one-third). Japan is the second largest market, importing or producing 630,000 tonnes (700,000 tons). The market continues to grow at about 3% y^{-1} as it has done for the last 25 years. Carbon blacks produced from pyrolysis oils are sulfur free and will find a use in this relatively valuable market where the prices of carbon blacks have been in the range of $450 - $700 per ton.

Feedstocks

Numerous feedstocks can be processed by fast pyrolysis into oils and chemicals. The major biomass categories are forestry and agricultural residues, yard waste, wood in construction and demolition debris, and feedstocks grown specifically for conversion to energy and chemicals. The estimated amount of each feedstock available for conversion is found in Table 1. Each category is discussed below along with a discussion of how the quantities were estimated.

Table 1. Estimated Availability of Selected Feedstocks for Biomass Conversion in the United States

Feedstock	Tonnes Per Year (Millions)	Tons Per Year (Millions)
Forest Residues	70	77
Agricultural Residues	64	70
Yard Waste	31	34
C & D Wood	9	10
Subtotal	174	191
Dedicated Feedstocks	227	250
Total	401	441

Each biomass category has different properties, costs and benefits as a feedstock for fast pyrolysis conversion processes. Some of the major issues are discussed as they specifically apply to pyrolysis. Many of the waste feedstocks can be free of charge or the operator can receive a tipping fee to dispose of the material. However, these are niche markets. As these waste feedstocks become a resource for several operations, a cost for the feedstocks is assigned. With dedicated feedstocks, a steady supply and quality is assured, but there will always be a higher cost involved with the feedstock.

Also, using waste material as feedstocks in the near term demonstrates the technologies and paves the way for dedicated feedstock systems that will be needed for long-term market expansion and stability. Dedicated feedstock systems would include short rotation woody crops such as hybrid poplars, and herbaceous energy crops such as switchgrass, and other native American grasses (Chum et al. 1993).

Forestry Residues

According to the U.S. Department of Agriculture (1992), the United States currently has 195 million hectares (483 million acres) of commercial timberland. Every year, this acreage produces 254 Mt (280 million tons) of timber material. Of this amount, 140 Mt (155 million tons), approximately 60%, are softwood products and 72 Mt (80 million tons) are hardwood products. The remaining 41 Mt (45 million tons) are logging residues.

Half of this residue is unrecoverable because it is damaged by insects, diseases or fire, or in the case of small branches and limbs trimmed during logging, is prohibitively expensive to transport. However, the remaining material, 20.5 Mt (22.5 million tons), can be recovered.

Once the material leaves the forest, it is used to make primary products such as saw timber, veneers, a variety of particle or composite boards, and pulp, from which paper and paperboard products are made. Approximately 50% of all the input material does not appear in the final products. Much of this mill residue such as sawdust, trimmings, and black liquor is being burned each year to generate power for lumber and pulp mills. Smaller trees are also being converted into composite boards.

However, not all of this waste processing material is used each year. Morris and Ahmed (1992) have estimated that 6.4 Mt (7 million tons) of sawdust is available each year along with 42.9 Mt (47.2 million tons) of other wood mill residues. These other residues include bark, wood chips, and wood shavings from sawmills. (Reliable statistics for these wastes and residues are difficult to find and the figures presented here are estimates that are likely to be under, rather than over estimates.)

Agricultural Residues

Morris and Ahmed (1992) summarized the annual availability of waste bioresources in the United States. A portion of their list includes available agricultural residues. They estimate that 50.5 Mt (55.6 million tons) of corn stalks, leaves, and sheaths from corn mills are available each year. Of this amount, 30% are returned to the field, 25-30% is mixed with hay for silage and 5% is used on chicken farms for bedding. This leaves 17-18 Mt (19-20 million tons) per year that is discarded.

The majority of wheat straw is burned in the field. Only 10-15% of the 31.2 million tons available each year is used as an absorbent and feed on farms and in compost. This leaves 24-25.5 Mt (26.5-28 million tons) available each year.

Morris and Ahmed also estimate that there are 18 Mt (20 million tons) of husks from other grain mills discarded each year, and 2.9 Mt (3.2 million tons) of peanut and other hulls from nut processing plants discarded. If these residue streams are all available for feedstocks for fast pyrolysis, there will be 62-65 Mt (68-71 million tons) of agricultural residues available each year.

The estimates for the availability of agricultural residues vary widely according to the source, much as those for forestry residues and wastes do. For example a recent survey of the Midwest states carried out by the Union of Concerned Scientists indicates a potential in 10 states alone of 85 Mt (93 million tons) of deliverable residue. Of this it was estimated that 18 Mt (20 million tons) could be delivered to the plant gate at 40 - 50 $/t over a collection radius of 56 km (35 miles). These agricultural residues were considered to be significantly more costly than those of the forest products residues in the same region (Brower et al. 1993).

Municipal Solid Waste

Wood waste currently entering landfills is primarily yard waste that includes tree and brush trimmings, grass and leaves from residential, institutional, and commercial sources. The U.S. Environmental Protection Agency (EPA) (1990) sampled the amount of yard waste to estimate the municipal solid waste composition. From 1960 to 1988 the percentage of yard waste to the total waste stream has decreased slightly, but in terms of per capita generation, there has been a slight increase.

In 1990, 32 Mt (35 million tons) of yard waste were disposed of in the United States. This is 17.9% of the total municipal solid waste generated every year. By volume, the yard waste comprised 9.8% or 46.7 million yards of the material sent to the landfills. In addition, 7.5 million tons of wood packaging material was discarded in 1990.

Turning yard waste into compost removes the material from the waste stream and is gaining public acceptance. The EPA (1990) estimated that less than 2% of the yard waste generated in 1988 (474,000 tons) was removed for composting. However, this amount is increasing each year as more states ban yard waste from landfills.

In addition to the large quantities of waste created by the United States each day, there are increasing disposal problems. For example, in 1964 there were 1600 landfills in New York that accepted municipal solid waste; in 1989, there were only 203 (Piasecki et al. 1990). Based on the existing landfill capacity, all existing landfills in New York will be closed by 1995. Currently many counties and cities are shipping their wastes out of the county or even the state for disposal. Tipping fees have increased dramatically, and in many areas have approached or exceeded $100 per ton for disposal. However, landfill capacity is not decreasing on an overall basis because the landfills that are closed are generally small and a large capacity exists at the remaining sites. Thus in some areas tipping fees are decreasing in response to competition for garbage. Waste disposal costs are extremely site specific, as are the county and municipal waste management strategies.

Construction and Demolition Debris

Construction and demolition (C&D) debris includes wood, brick, glass, metal, roofing and pallets. The majority of landfills do not accept these materials. Landfills that are strictly for C&D material exist and were not tightly regulated in the past. However, these landfills are currently being regulated much more stringently and the cost of operating them has increased. The tipping fees to disposers have also increased, and these higher costs are passed on to the consumer through building and remodeling fees.

Wood is 25% of the C&D waste stream according to the New York State Energy Research and Development Agency (NYSERDA) (1990). The Northeast Industrial Waste Exchange recently reported on C&D disposal in Onondaga County (Naef 1991) and the exchange estimates that the county disposed of approximately 91 kt (100,000 tons) of C&D waste in 1989. This number is conservative because it does not take into account material that was buried in backyards, dumped illegally or transported outside the county. They estimate that wood comprises 35%-40% of the C&D material. It appears that wood, much of which can be used as a feedstock for pyrolysis, ranges from 25%-40% of the C&D stream depending upon the area.

Piasecki et al. (1990) estimated the breakdown regarding the amount of C&D waste generated in New York each year. These analyses can be generalized to the United States and are used as the basis for the calculations below. However, these numbers are estimates only and are not supported by measurements of actual C&D generation.

Approximately 164 Mt (180 million tons) of municipal solid waste (MSW) is generated per year in the United States according to Franklin Associates, who studied this question for the Environmental Protection Agency (EPA) in 1990. Also, an average of 0.33 kg or 0.72 pounds per capita per day of C&D waste is generated nationwide. The United States, with a population of about 253 million, generates about 29 Mt

(32 million tons) per year. Assuming wood is 25% of the total, the amount of wood available is 7.3 Mt (8 million tons).

A different method of estimation, based on a report on using waste wood for fuel for the Northeast Governors Coalition by Donovan (1990), assumes 3,600 tonnes (4,000 tons) per day of C&D waste wood for the New York metropolitan area (including Connecticut and New Jersey)—a population of about 15 million people. This equates to 1.3 Mt (1.5 million tons) of C&D waste. If this is extrapolated to the United States population it would equal 22 Mt (25 million tons) of C&D each year, or 5.5 Mt (6.2 million tons) of wood available.

Franklin Associates estimates that the C&D waste steam is about 24% of the total municipal solid waste stream. For 176 Mt (196 million tons) of municipal solid waste in the United States, the total C&D would be about 42 Mt (47 million tons). Again, assuming wood is 25% of the total, the amount of wood available is 10.5 Mt (12 million tons).

These three estimates place the amount of C&D wood waste generated in the United States each year in the 5.5 - 10.5 Mt (6 - 12 million tons) category.

Dedicated Feedstock Supply Systems

Several overviews of dedicated feedstocks for energy conversion have been done by Chum et al. (1991, 1993) and Turnbull (1993). Multiple species of short rotation woody crops and high yield herbaceous crops have been developed by the Departments of Energy and Agriculture.

A recent study by the Office of Technology Assessment (OTA) estimates that energy crops could be grown on 40 Mha (100 million acres) in the United States. The Department of Energy estimates that between 14 - 80 Mha (35 - 200 million acres) of land could be made available for energy crop production. EPRI (Turnbull 1993) used a conservative estimate of 20 Mha (50 million acres). If a conservative production figure of 11.2 t ha^{-1} y^{-1} (5 tons/acre/year) is used, this yields 227 Mt (250 million tons) per year. As new cultivars are developed with higher productivity, this overall biomass potential is expected to increase.

Based on the above figures, Turnbull estimates that energy crops could add $12 billion to the farm sector economy. The majority of this income is expected to stay in the small to medium size farms in rural areas.

Economic Considerations (for 36 TPD Future Facilities Using Waste)

Energy Conversions Inc., a division of Interchem, anticipates that future units will cost approximately $1.5 million as one time engineering fees that added about $200,000 in costs for the second generation unit, will not be associated with future models. The following economic analysis is based on a future 36 TPD unit costing $1.5 million.

Oil is produced at a rate of 870 liters (wet basis) per hour (230 gallons per hour) and sells for $0.11/liter ($0.40 per gallon). Char is produced at a rate of 0.21 tonnes per hour (0.23 tons per hour) and sells for $88/tonne ($80/ton). The incoming wood feedstock is a mix of 50% pallets at 10% moisture and 50% green waste at 50% moisture. Tipping fees of $11/tonne ($10/ton) will provide an income from the wood (on an as received basis). The plant (including the feedstock preparation) will operate 24 hours per day for 330 days per year. The loan term is for 7 years at 12.5% interest in a 100% debt financing arrangement.

Therefore, the annual income (in thousands of dollars) can be estimated as follows:

Oil	729
Char	146
Total	875

The annual expenses are listed below:

Principal and Interest	323
Wood	(185)
Labor	167
Maintenance	45
Electrical	129
Natural Gas	150
Overhead	52
Total	681

This gives a net income prior to taxes and production tax credits of $194k. An overall debt coverage of 1.59 is obtained during the first year of operation.

Analyses of the economics of 250 and 1000 TPD plants were made by Gregoire and Bain (1993). These analyses show the economy of scale that occurs with the larger units. Chum and Power (1991) analyzed the economics of producing phenolic compounds at the 250 and 1000 TPD scale. This process is very economical even when only one product is obtained. The simple pay back period for installation of the 250 TPD unit is about two years if the difference between the selling price of phenol and the unamortized production cost of the phenolic product is maintained at $0.2/lb for a nearly $13 million investment.

Environmental Considerations

The environmental impacts of properly designed fast pyrolysis processes are expected to be very small. A 36 TPD unit is expected to produce very low emissions. Low NO_x burners are used in the furnace, and the process heat is provided by burning the off-gases. Only 1.25 tons per year each of carbon monoxide and nitrous oxide will be emitted. Particulates, and sulfur dioxide emissions are expected to be very low. The oil has a Reid Vapor Pressure of 0.4 psi, which minimizes the anticipated volatile organic carbon (VOC) emissions from the oil tanks and loading operations.

All of the economic and environmental evaluations reported have been made for clean wood feedstock. However, when using C&D woods, care needs to be taken with CCA treated wood, painted wood (lead-based paints) and possibly contaminated pallets. Each of these feedstocks will require special studies with extensive monitoring of air emissions, product and ash composition before they can be used as feedstocks in commercial applications.

One of the complicating issues for fast pyrolysis commercialization occurs when the developer applies for an operations permit. Because the technology is new, there are no standards or classifications nationwide for fast pyrolysis. State and local environmental permitting agencies have classified fast pyrolysis of clean waste wood anywhere from a manufacturing facility, a recycling facility or, in one case, as a municipal solid waste incinerator. Depending upon how a state or county chooses to work with new technology, permits have taken Interchem anywhere from two weeks to more than two years. The normal length of time is one to four months.

Permitting for fast pyrolysis plants will continue to be site specific. There are many sites throughout the United States where the permitting process is done principally if the process has been carefully monitored at smaller scales. Other cities and towns require that the process be scaled up first at another location and that monitoring of environmental data takes place prior to issuing permits. We expect to continue to encounter these increased concerns from the public and private sector alike for developing environmentally conscious manufacturing and processes.

When dedicated feedstocks and biomass derived residues are used, the contribution of greenhouse gases to the environment is negligible (U.S. DOE 1993). This contrasts to the current fuel mix that emits over 600 metric tons of CO_2/Gigawatt-hour.

Future Role of Fast Pyrolysis

We believe that there is a large potential for fast pyrolysis processing of biomass. A conservative estimate states that initially 2000 TPD of processing capacity can be brought on line per year. This could handle 600 kt (660,000 tons) of feedstock per year. From Table 1 of available feedstocks in the United States, this is only 0.35% of the waste feedstocks available each year and 0.15% of the potentially available feedstocks. The potential exists for significantly penetrating these technologies throughout the United States and into other countries with substantial renewable resource potential. Widespread deployment of this technology will increase regional employment throughout the United States and also overseas.

An initial market will develop in the waste feedstock arena, because at the 36 TPD current scale, tipping fees of $11/tonne ($10/ton) are needed to economically produce fuel oil. As larger scale units (100, 250 and 1,000 TPD) are developed, built and operated, the economy of scale will permit profitable economics at $44/tonne ($40/ton) feedstock costs at the largest scale (Gregoire and Bain 1993). The economics also improve tremendously as the oil is fractionated to produce higher value chemical products.

Fast pyrolysis has been identified as one of the technologies for producing power from biomass. Currently, 6,500 megawatts of electricity is produced from biomass. DOE's growth projections indicate that more than 22,000 megawatts of biomass electric capacity will be on line by 2010. The Electric Power Research Institute estimates, on the basis of resource availability, that the potential biomass power capacity could reach 50,000 megawatts by 2010. There is a substantial potential for low cost electric power production from biomass. The impacts of this increased power production on jobs and regional employment are described in a recent issue of Biologue (Meridian and Antares 1992, Wood and Whittier 1992).

Another area expected to have significant growth is the use of fast pyrolysis to convert the organic portion of municipal solid waste, not just the wood fraction, into gasoline additives. This technology is still in the research phase but looks very promising. Throughout the world there has been almost 20 years of research, development, and demonstration of fast pyrolysis processes using biomass throughout the world. As a result the technology is on the steep part of the learning curve, and has spawned several concepts that are ready for commercial development. High value fast pyrolysis products such as food flavors are already in the market place in the United States. In other countries, especially Brazil, producing charcoal by traditional slow pyrolysis methods is a large scale commercial activity.

It is worth recalling that the Burton cracking process patent for refining crude oil was issued in 1913, almost 70 years after the first oil wells were placed in production. The need for kerosene for lighting resulted in a large research and development effort in the 1890s and it is clear that technology commercialization and technology deployment is a multi-decade process in the energy and chemicals industries (Yergin 1990). This prognosis stands even though technologies are available for processes as fundamentally innovative as oil refining was then, and biomass refining is today. Developing biomass processes and a completely new philosophy of natural resource use has just begun, but we think there is a very bright future ahead when we consider the state of the global environment and the need for sustainable development.

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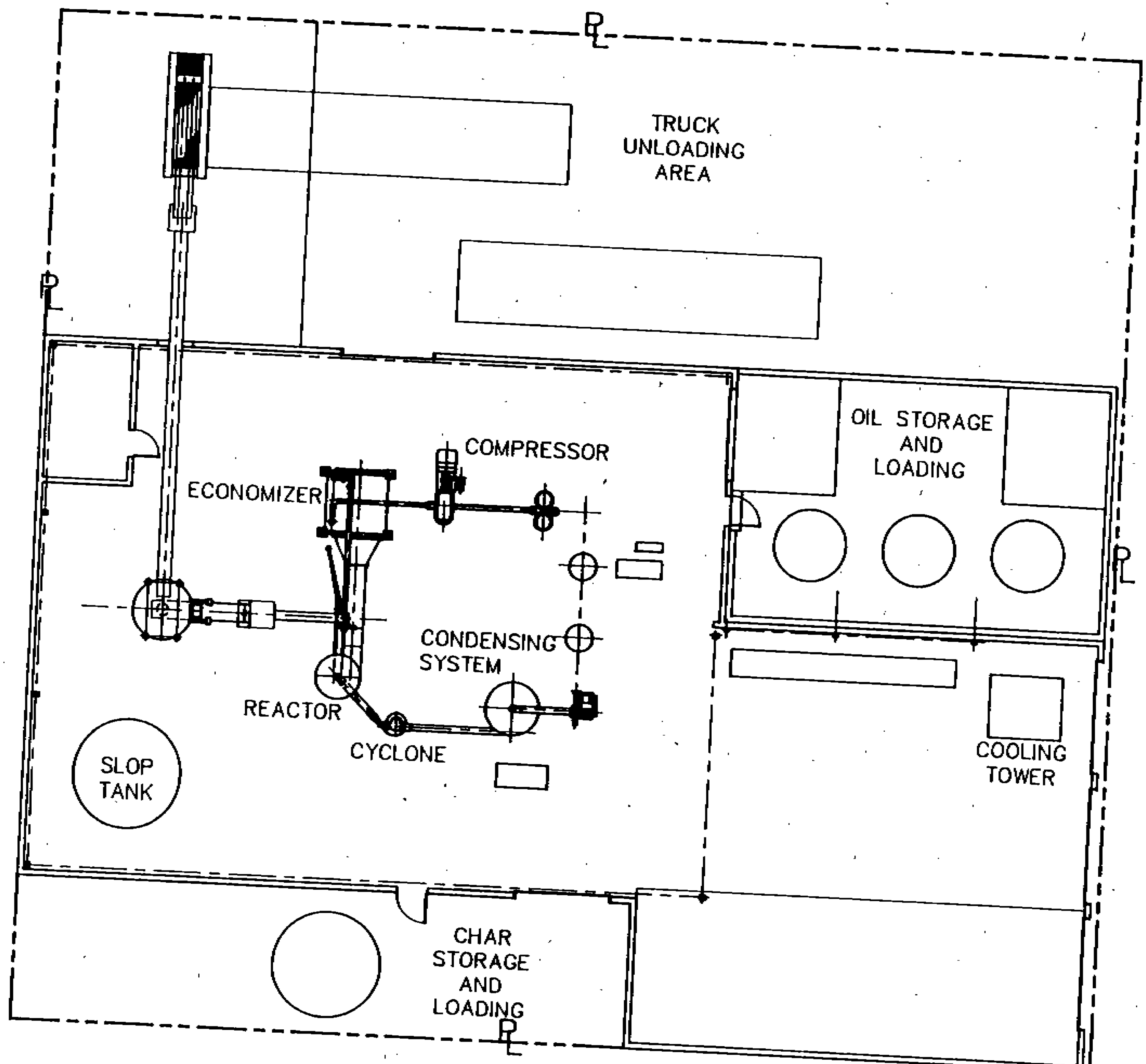


Figure 1. Site layout for a 36 TPD fast pyrolysis facility.

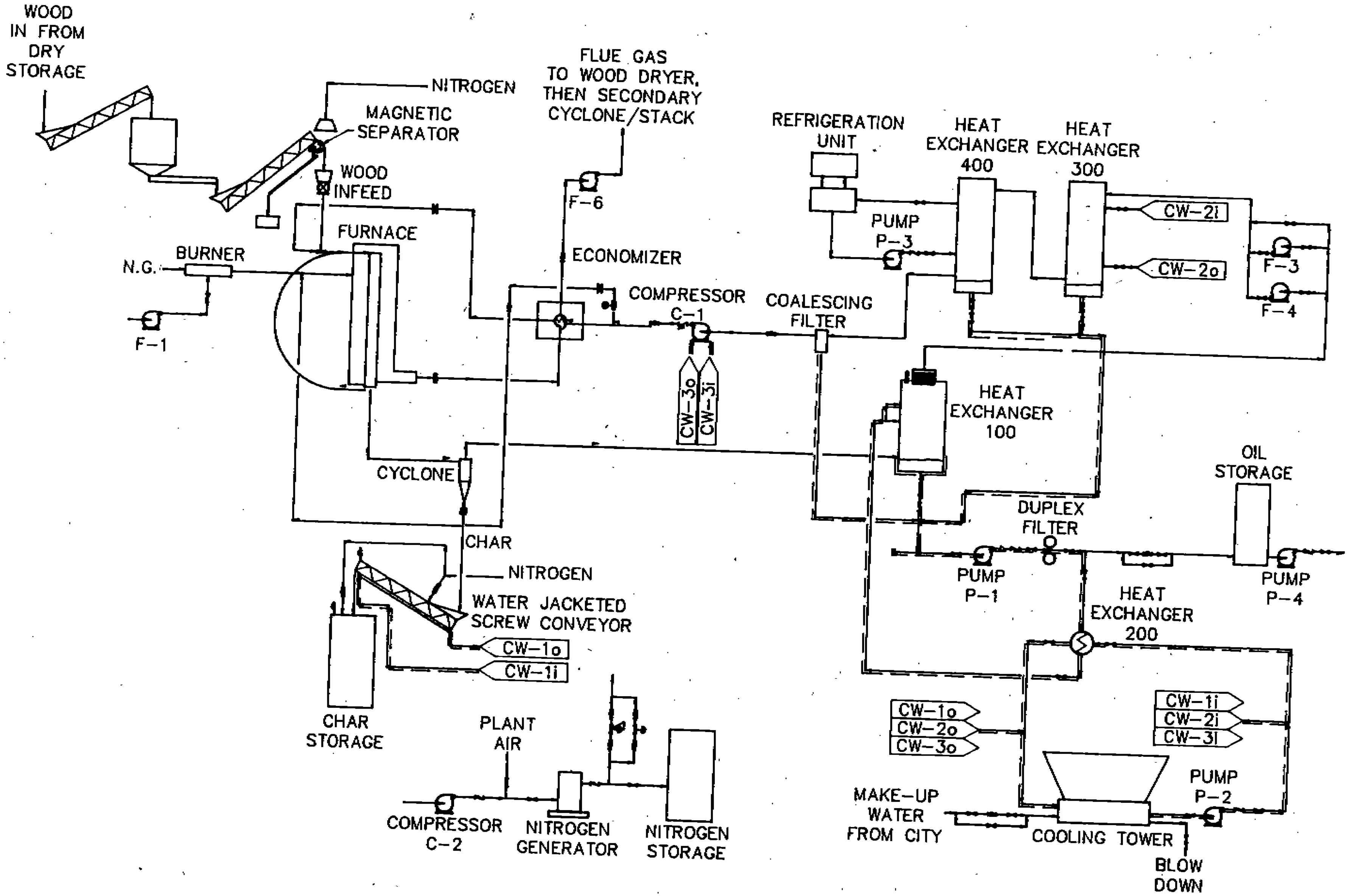
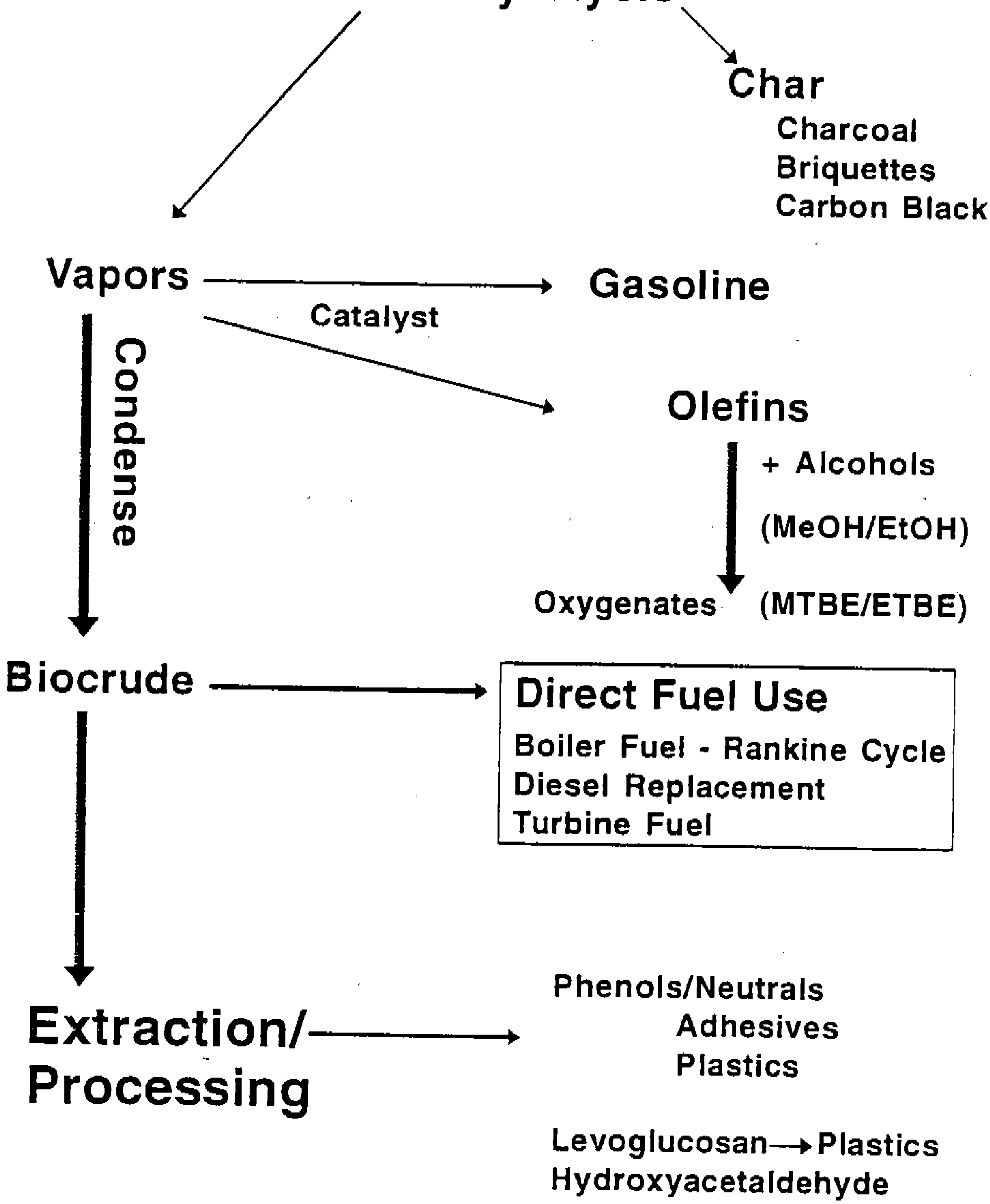


Figure 2. Process flow diagram for the ablative fast pyrolysis system.

Figure 3.
Fast Pyrolysis



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