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TECHNOLOGY DEVELOPMENT AND COMMERCIALIZATION OF THE RENUGAS® PROCESS

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1 BACKGROUND

The RENUGAS® process is a pressurized fluidized-bed biomass thermal gasification process developed by the Institute of Gas Technology (IGT) with support from the U.S. Department of Energy (DOE) and private industry. During the past year, it has been proven successfully at the process development unit (PDU) scale using bagasse from a sugar mill in Paia, Hawaii, as the feed to the gasifier. This PDU-scale program was sponsored by DOE under the Biomass Gasification Scale-Up Demonstration Cooperative Agreement with the Pacific International Center for High-Technology Research (PICHTR), Honolulu, Hawaii. The objective of the IGT PDU test program was to determine the gasification characteristics of bagasse that will constitute the basis for scale-up to the 100-ton-per-day demonstration unit to be built by PICHTR at the Hawaiian Commercial and Sugar Company plant at Paia, Maui.

2 RENUGAS PROCESS DEVELOPMENT UNIT

The IGT RENUGAS PDU is a fluidized-bed gasifier with a nominal capacity of 12 tons per day of biomass feed. The entire unit, shown in Figure 1, extends over 50 feet in height, has a 21-foot-high by 11.5-inch-ID reactor, with an Incoloy 800H liner surrounded by about 12 inches of bulk fiber insulation inside a 3-foot-OD carbon steel pressure vessel. The feed hopper and associated solids-handling equipment are designed for continuous feeding to the pressurized gasifier. Installed above the continuously pressurized live-bottom metering feed hopper is a 24-inch-ID by 6-foot-high lockhopper vessel equipped with quick-opening and closing slide gate valves, with provisions for cyclic pressurization with nitrogen and depressurization during the feed-loading operation. The metering feed hopper vessel is 4 feet in diameter and 9 feet high. It is equipped with a three-screw live bottom, which meters and discharges the biomass feed into the gasifier via a transport-injector screw. The piping between the gasifier and the cyclone, as well as the piping between the cyclone and the downstream water spray quench, is refractory-lined carbon steel pipe. Partial quenching of the hot product gases downstream of the cyclone reduces the gas temperature to about 800°F before the product gas is flared.

The PDU also utilizes lockhopper systems to load the inert material used as a fluidization medium and to collect the carry-over solids removed by the cyclone.

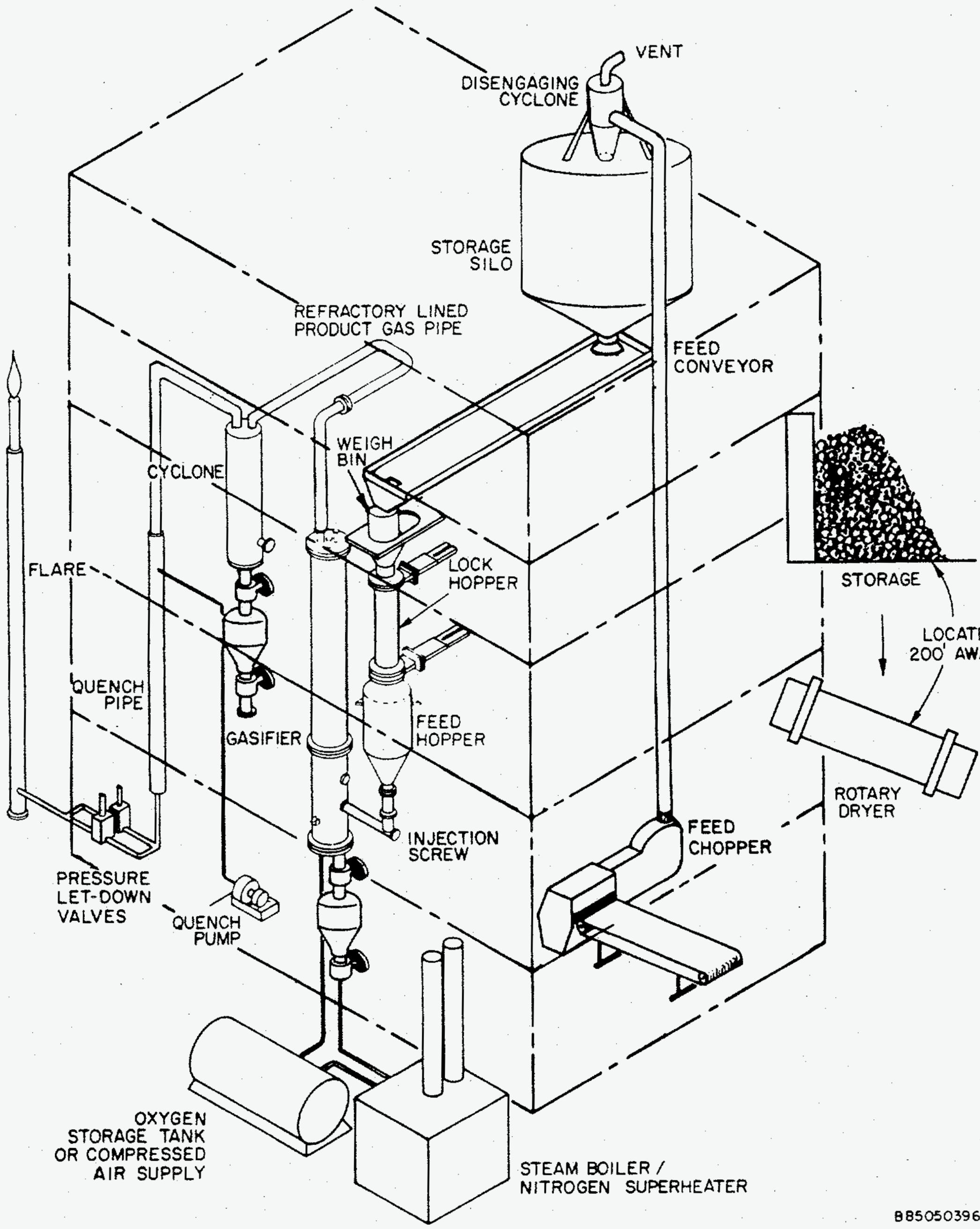

Figure 1. Isometric View of the RENUGAS PDU Equipment.

Conventional instruments were adapted to monitor flows, pressures, and temperatures. The fluidized-bed density and level were determined through differential-pressure measurements made at temperatures up to 1800°F and pressures up to 500 psig. Fluidized-bed density was determined by using the pressure difference between two fixed points immersed in the fluidized bed; overall fluidized-bed height was measured using the total pressure drop across the entire gasifier and the measured value of the bed density. Accurate knowledge of these two variables is an important criterion for proper control of the RENUGAS fluidized-bed system.

The biomass feed rate to the gasifier was monitored by a hydraulic load cell measuring feed batches loaded into the weigh bin of the feed system. The weight of a single batch of chopped bagasse in the weigh bin is approximately 55 pounds. The solids from the weigh bin were discharged into the lockhopper and then into the feed hopper, which contains live-bottom feed metering screws.

The solids level in the feed hopper was monitored by a capacitance probe extending vertically into the feed hopper. The solids feed rate to the gasifier was adjusted through a variable-frequency AC motor-drive system controlling the metering screw rotational speed.

The PDU pressure was maintained by regulating the flow of the gasifier product gas through a pressure letdown valve downstream of the quench system. Earlier pioneering work by IGT in adapting severe-pressure letdown valves for coal gasification processes used commercial rotary-action choke valves (with tungsten carbide disks with diamond lapped matting surfaces) that were modified with features that significantly improved service life and control performance.

2.1 GAS SAMPLING

The gases, liquids, and solids from the product gas stream leaving the gasifier were sampled through two sampling systems: the gas analyzer system (GAS) and the isokinetic sampling system (ISS). Both streams were withdrawn at a common sampling point close to the gasifier exit, with each sample probe extending into the center of the refractory-lined product gas line, as shown in Figure 2. The particulates and condensates were withdrawn by the ISS probe that faces into the center of the flowing gas stream and withdraws approximately 1% of the total gas flow at isokinetic conditions, that is, at a velocity approximately equal to the estimated gas velocity in the product gas line. Entrained particles were trapped by a filter and the clean gas flowed through a water-cooled condenser where condensibles were removed.

The GAS probe, unlike the ISS probe, faces away from the direction of flow in the product line to minimize solids withdrawal. The sample lines are heated electrically to prevent condensation before the gas enters an on-line gas chromatograph to analyze for hydrogen, carbon monoxide, carbon dioxide, nitrogen, argon/oxygen, methane, ethane, ethylene, benzene, toluene, and xylenes.

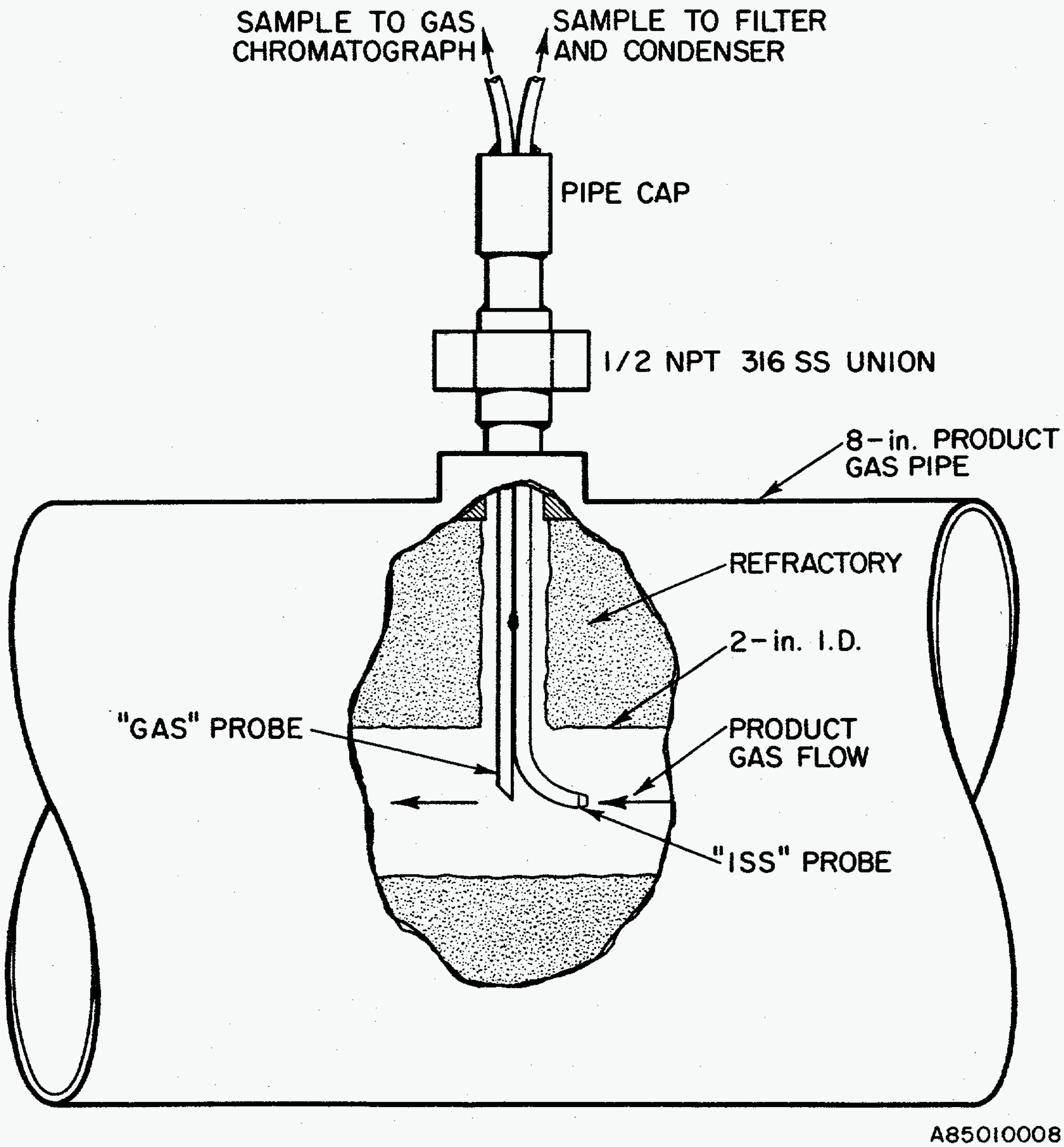

Figure 2. PDU Dual Sampling Probe.

2.2 BAGASSE HANDLING AND CHARACTERIZATION

Approximately 37 tons of bagasse were shipped from the Paia sugar mill to Chicago in two overseas containers. The bagasse arrived in good condition, although the moisture content was variable (from 18% to 22% moisture in the middle to 67% near the walls) rather than a uniform 30% moisture reported at the shipping point. The as-received bagasse had a low bulk density of about 2 to 3 pounds per cubic foot with fibers about 3 to 6 inches long. The 18% to 22% moisture material in the center of the container was of an appropriate moisture level for the PDU tests, but the material would not flow easily through the various feed system components in the PDU system. Consequently, the bagasse was subjected to size reduction using an existing hammermill, which reduced the size of the fibers and increased the bulk density to 6 to 7 pounds per cubic feet. However, hammermilling produced smashed/twisted fibers that caused clumping and reduced the bagasse flowability.

After observing that hammermilling is inappropriate for reducing the length of the bagasse fibers, a forager-harvester farm implement (a "chopper") was used and proved quite satisfactory for reducing the bagasse fiber length to 1/8 to 3/4-inch to yield a bulk density of 7 pounds per cubic foot. The flowability of the chopped bagasse improved significantly. The chopped bagasse produced 60% higher feed rates than the hammermilled bagasse at the same feed-screw setting. Consequently, a New Holland Model 892 chopper was obtained for processing the bagasse to appropriate fiber lengths for the PDU tests.

2.3 PDU SYSTEM MODIFICATIONS

Although the PDU feed-handling system has been used successfully to handle several types of woody biomass fuels and refuse-derived fuels (RDF), the bagasse feed required several modifications to ensure a steady, uniform flow of the chopped bagasse. These modifications included 1) installation of a steeper, 60°-angle discharge cone to replace the existing 30°-angle cone at the bottom of the vibrating bin storage silo, to improve the bagasse flow; 2) reduction of the spacing between the vibrating cones that meter the silo discharge to regulate the flow of the chopped bagasse; 3) installation of a more sensitive feed-level sensor in the feed hopper; 4) addition of an extension to the weigh bin discharge chute and the construction of a new discharge chute to the weigh bin; and 5) reversal of the direction of rotation of the center live-bottom meter bin screw, so that it would rotate in a direction opposite to that of the two outside screws and thus avoid "rafting" of the feed over the screws and nonuniform discharge from the meter bin. These modifications greatly improved the bagasse feed and handling characteristics of the system.

2.4 PDU TEST PROCEDURE

The PDU test procedure first involved a cold nitrogen system pressure check at 1.1 times the operating pressure selected for the test, that is, a 330 psig pressure test for 300 psig operation. At this time, certain instruments were checked for operation, the purge flow to the fluidized-bed differential-pressure taps were balanced, and then the system was slowly depressurized to atmospheric pressure.

PDU start-up operations then began by starting the superheater to heat the fluidization-nitrogen gas to preheat the gasifier to about 700°F. The system pressure was gradually raised during this time and the charge of inert fluidized-bed material was slowly added to the gasifier through the inert material lockhopper. The steam boiler was started, but the steam was diverted through a bypass until it was required to replace the fluidization-nitrogen flow to the gasifier.

When the gasifier fluidized bed reached 700°F, about 125 pounds of charcoal was loaded into the feed hopper and slowly fed to the fluidized bed. After feeding about half of the charcoal, oxygen was trickled through the fluidizing nitrogen nozzle to ignite the char and was gradually increased to bring the fluidized bed to test temperature and held at this temperature until the downstream piping temperature exceeded condensation temperatures. The test feed material (bagasse) was then loaded into the feed hopper after weighing and recording each charge in the weigh bin. When the charcoal was consumed, gasification began as bagasse was fed to the gasifier at about one-third to one-half the test feed rate for about 1/2 hour and the fluidizing nitrogen was replaced with steam. The solids feed rate was then increased to the full rate for the test and the steady-state operation started.

Steady-state operation was confirmed by monitoring CO concentration from the gas sample probe. After 2 hours of steady-state operation, hot-gas sampling was started and repeated hourly to collect samples for char, oil, and ash analysis. Dry gas compositions were determined by the on-line gas chromatograph every 8 minutes for the major gaseous components and every 16 minutes for hydrocarbons including C_1 - C_6 alkanes, olefins, benzene, toluene, and xylenes.

Shutdown was initiated by allowing the feed in the feed hopper to be depleted, as indicated by the reduced CO level in the product gas. The oxygen was then shut off, the steam input to the gasifier was replaced by nitrogen, and the natural gas input to the steam superheater was shut off. Pressure and nitrogen input flows were gradually reduced as the temperature fell. When the gasifier temperature reached 500°F, fluidization and purge flows were stopped and the gasifier was allowed to cool for 2 days to ambient temperature.

3 TEST RESULTS

After shakedown tests and initial gasification test runs, a successful bagasse gasification test was carried out at an average fluidized-bed temperature of 1568°F and system pressure of 310 psig. The test operated smoothly from start-up to shutdown with a bagasse feeding period of 6.3 hours and achieved 96% carbon conversion. The as-measured PDU test data are shown in Table 1. As-measured PDU material-balance data adjusted to 100% are shown in Table 2. The bagasse gasification characteristics were found to be similar to those observed with woody biomass in a previous PDU test program [1].

Table 1. As-Measured PDU Test Data.

Hawaiian Bagasse Test HBT-2

Date of Test:	March 5, 1992
Test Duration:	6.33 hours (14:10-20:30)
Steady-State Period:	16:50-17:50
Test Conditions:	
Temperature	1568°F
Pressure	310 psig

Material Input Data	lb/h	Temp, °F
Biomass (wet)	559.87	68
Steam to Nozzle	191.00	702
Steam to Ring	319.00	886
Oxygen	156.00	702
Nitrogen	198.00	68

Oxygen, lb/lb feed (wet)	0.28
Steam, lb/lb feed (wet)	0.91
Superficial Gas Velocity, ft/s	1.58
Fluidized-Bed Height, ft	5.20
Fluidized-Bed Density, lb/ft^3	92.0

Material Output Data	lb/h
Cyclone Char	10.27
Condensate	633.82
Aqueous Phase	617.88
Oil Phase	15.94
Dry Product Gas	742.89

Table 1, Cont. As-Measured PDU Test Data.

Hawaiian Bagasse Test HBT-2

Temperature at Gasifier Outlet: 1450°F

	Prod. Gas Comp., vol %		
	Wet	Dry	Dry, N_2-Free
H_2	5.88	13.36	18.13
CO_2	12.19	27.72	37.58
C_2H_4	0.09	0.20	0.28
C_2H_6	0.07	0.15	0.22
O_2/Ar	0.04	0.10	0.12
N_2	11.50	26.25	--
CH_4	5.60	12.72	17.26
CO	8.47	19.25	26.11
C_3H_6	0.001	0.003	0.003
C_6H_6	0.11	0.26	0.34
H_2O	56.01	--	--
Molecular wt, lb/lb mole	22.2	27.6	27.4
Gas Yield, SCF (wet)/lb feed (wet)		41.4	
Gas Yield, SCF (dry)/lb feed (dry)		22.3	
Gas Heating Value,* Btu/SCF (dry)		249.2	
Gas Heating Value* (dry, N_2-free gas)		338.1	
Cold Gas Thermal Efficiency (dry, N_2-free)		0.67	
Carbon Conversion to Gases and Liquids, %		96.0	

* Heating value of oils at 16,700 Btu/lb not included.

Table 2. 100% Material and Energy Balance for PDU Test HBT-2. (Basis: 1 Hour; All Units in Pounds Unless Otherwise Noted.)

	C	H	N	S	O	Ash	Total	10^6 Btu
Input, lb								
Biomass	226.91	26.11	0.93	0.15	187.72	15.14	456.95	3.74
Moisture	--	11.52	--	--	91.40	--	102.92	--
Oxygen	--	--	--	--	156.00	--	156.00	0.02
Nitrogen	--	--	200.70	--	--	--	200.70	--
Steam	--	57.07	--	--	452.92	--	509.98	0.71
Total	226.91	94.69	201.63	0.15	888.04	15.14	1426.56	4.47
Output, lb								
Char (entr)	9.05	0.12	0.05	0.00	0.15	15.14	24.51	0.15
Moisture	--	0.06	--	--	0.46	--	0.52	--
Dry Prod. Gas	203.09	22.26	200.70	0.15	326.99	--	753.19	2.93
Oils/Tars	14.09	0.97	0.01	0.00	1.09	0.00	16.17	0.28
Aqueous Phase	0.68	71.29	0.86	0.00	559.34	--	632.18	1.09
Total	226.91	94.69	201.63	0.15	888.04	15.14	1426.56	4.45
Out/In, %	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.6

The oil yield from the bagasse gasification is indicated in Figure 3 together with results from earlier PDU gasification tests with woody biomass under approximately the same experimental conditions. The quantity and distribution of the liquids from the bagasse test were found to be similar to the liquids analyzed in previous tests with Wisconsin whole tree chips. Although there are slight variations in the distribution of the liquid components, there are no significant differences [1].

These PDU test results were also adjusted for both steam-oxygen-blown gasification conditions and steam-air-blown gasification conditions expected for the 100-ton-per-day demonstration gasifier. The process design for this bagasse demonstration gasifier was prepared for the cases of steam-oxygen-blown and steam-air-blown gasification by scaling the adjusted bagasse feed rates for the PDU system to the 100-ton-per-day demonstration plant capacity. The detailed design of the demonstration plant is now in progress and the procurement of long-lead items and construction will begin following the receipt of necessary environmental permits.

4 TECHNOLOGY COMMERCIALIZATION

The RENUGAS demonstration project in Hawaii will be tested for process scale-up and long-term performance to evaluate its application for power production. The test program will also include selected oxygen-blown gasification tests to evaluate synthesis gas production for oxygenated fuels. Concurrently with the demonstration project,

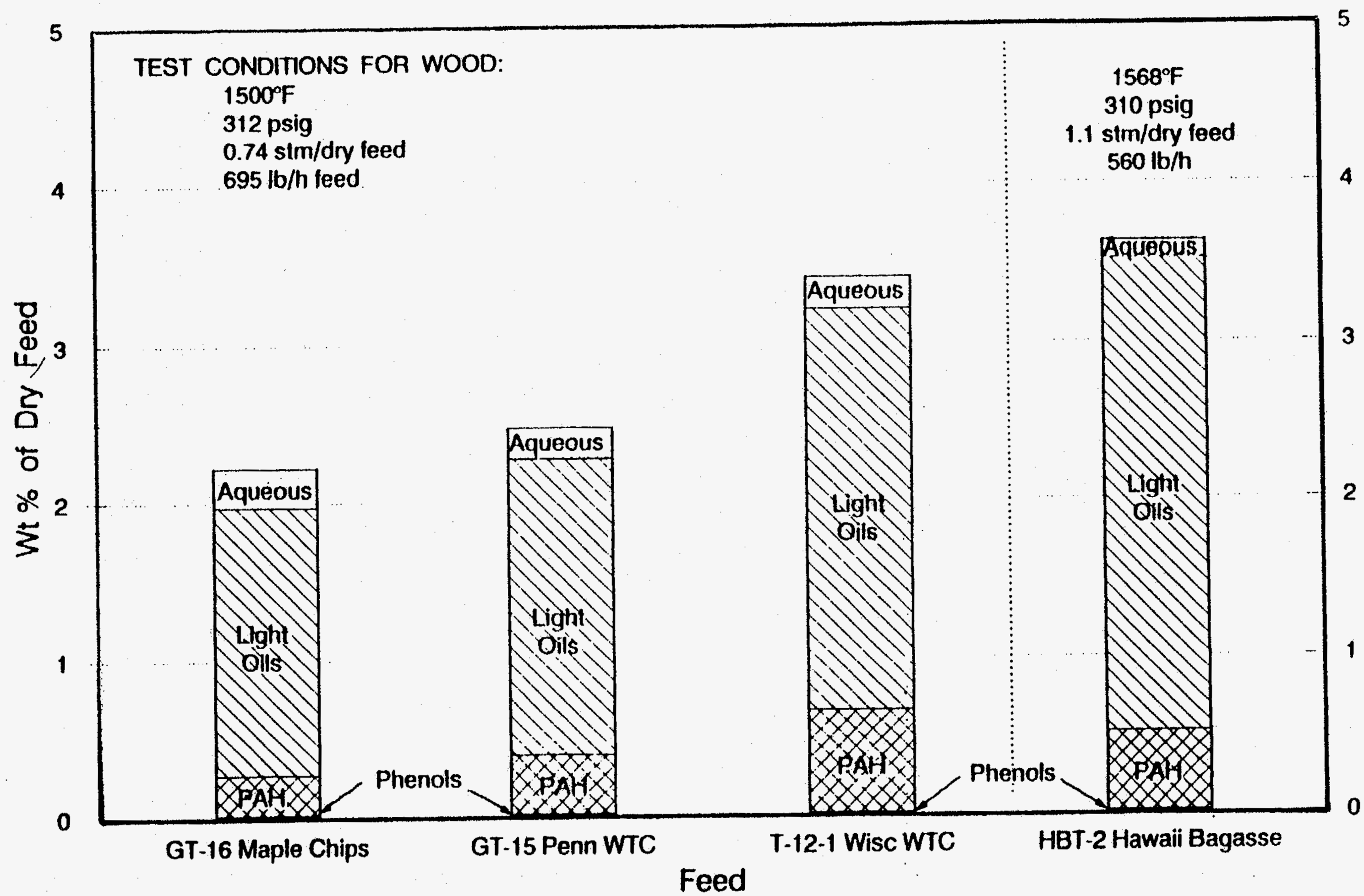

Figure 3. Oil Yield as Function of Feedstock.

IGT has begun negotiations with several parties for licensing the technology for commercial applications. To date, a license agreement has been signed with Enviropower Systems, Inc., Tampere, Finland, a joint venture of Tampella Power, Inc., of Finland and Vattenfall Energisystem of Sweden.

5 ACKNOWLEDGMENT

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6 REFERENCE CITED

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