Presented at : Fourth Biomass Conference of the Americas
August 29 - September 2, 1999
Oakland, CA USA

Camp Lejeune Energy from Wood (CLEW) Project

John G. Cleland[a] and Carol R. Purvis[b]

[a]Research Triangle Institute, PO Box 12194, Research Triangle Park, NC 27709-2194, USA

[b]U.S. Environmental Protection Agency, National Risk Management Research Laboratory, MD-63, Research Triangle Park, NC 27711, USA

This demonstration project converts wood energy to electrical power, and provides waste utilization and pollution alleviation. The 1 MWe plant operates a reciprocating engine-generator set on synthetic gas from a down-draft wood gasifier. This paper discusses plant descriptions, operational characteristics, performance data, and needed modifications.

1. PROJECT OBJECTIVES, ORGANIZATION, AND TECHNOLOGY CHOICE

The Camp Lejeune Energy from Wood (CLEW) project has been undertaken to demonstrate that small-scale wood-to-electricity plants can provide:

- reliable and commercially competitive power generation from a technology that has not yet been demonstrated at this scale;
- a non-polluting energy source using renewable fuel without net generation of greenhouse gases; and
- an economical alternative to landfilling wood residues and providing or supplementing power for government installations, industrial sites, rural cooperatives, small municipalities, and remote regions of developing countries.

A wood gasification plant designed for about 1 MW electrical power output has been installed and operated at the Marine Corps Base at Camp Lejeune, NC. This demonstration project is sponsored by the U.S. Environmental Protection Agency (EPA) and the Department of Defense Strategic Environmental Research and Development Program. The Research Triangle Institute (RTI) is working under a Cooperative Agreement with EPA to complete testing and demonstration. Other participants are the Marine Corps, North Carolina Department of Commerce, and Thermal Technologies Inc.(TTi).

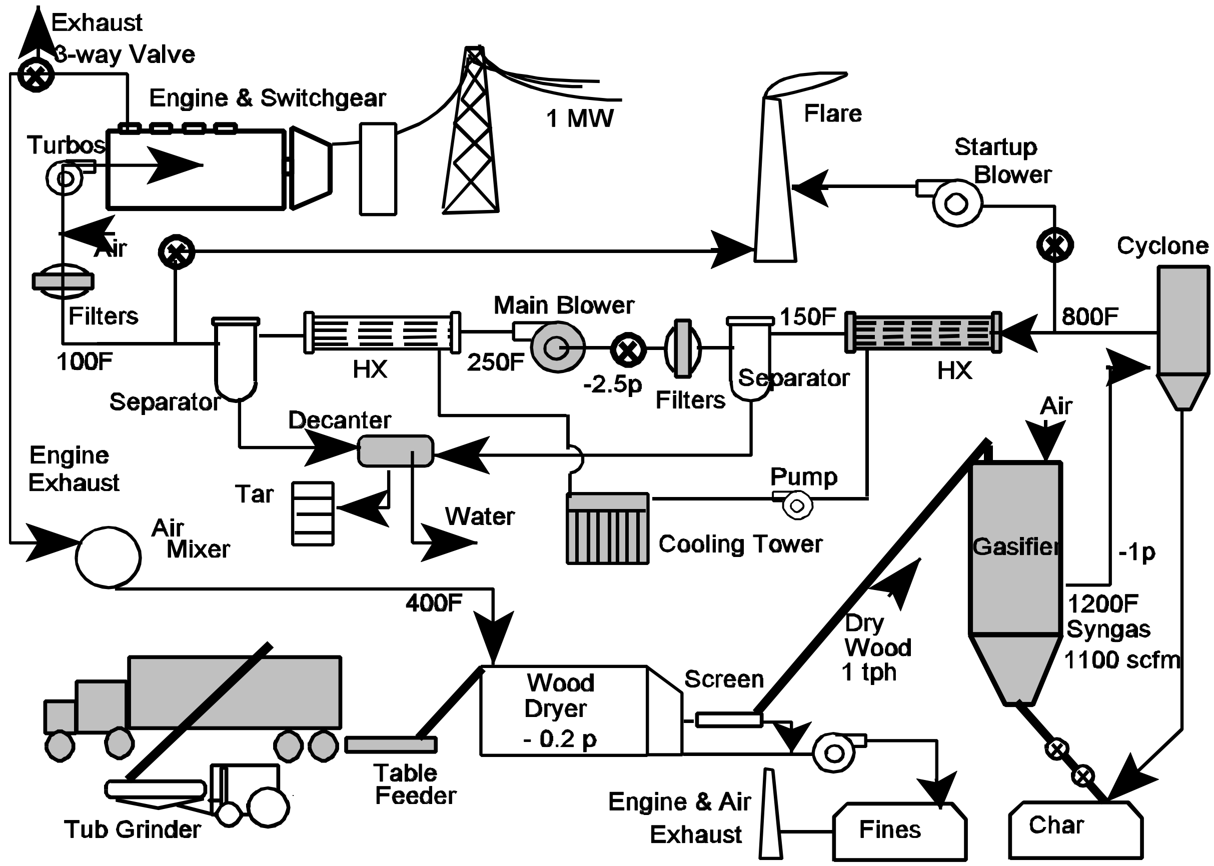
The EPA and RTI began the project with consideration of several biomass technologies, including: 1) wood combustion boiler with a steam turbine; 2) combustion boiler and heat exchanger to drive a hot air turbine; 3) gasification reactor supplying a gas-fired boiler with a steam turbine; 4) gasification reactor supplying a gas turbine; and 5) gasification reactor supplying an internal combustion (IC), spark ignited, reciprocating engine. The last option was chosen because the others are either proven, conventional techniques; not cost competitive or overly complex at small scale; or being demonstrated elsewhere. Although gasification for IC engines at commercial scale has encountered several experimental failures in the past (primarily because of tar and soot contamination), improved gas cleaning concepts and the advantages shown in Table 1 supported the selection.

Table 1
Three advantages of the design

Small Scale Plant	< 2 MW plant allows use of wood residues within short transport distance -- over an area typical of that allotted to landfill wood collection; guaranteed fuel availability; no need for deforestation or problematic "tree plantations;" fast installation; matches scale of existing engine-generator power plants; and ideal for moderate-size industrial plants, villages.
Downdraft Gasifier (Cocurrent Gas and Wood Flow)	Technology has matured over 70 years; tars are cracked in the char bed below the pyrolysis zone; activated carbon can be produced from char, at a value near that of the electricity co-produced; no hot gas filtration; vacuum system eliminates gas leaks, allows light-weight piping; large fuel bed gives process stability; large wood particles reduce fuel preparation energy requirement and allow bulk drying; simple control; and low labor requirement.
Reciprocating IC Engines	Thousands of existing engine-generators can easily convert to wood gas, reducing power costs as much as 80% in isolated regions; engine exhaust is very good for wood drying; no complex steam cycle or turbines are needed; and, while gas to the engine must be cooled, heat can be recovered as steam and hot air.

2. PLANT DESCRIPTION AND OPERATION

The plant incorporates a moving-bed bulk wood dryer; a downdraft, moving-bed gasifier utilizing hogged wood residues; a gas cleaning and cooling system; and a spark ignition engine, as illustrated in Figure 1. The plant utilizes only wood residues diverted from the Base landfill. The tub grinder and trommel screen load wood on walking floor trailers which transfer the fuel by automated conveyors into a moving-floor, low-cost, bulk dryer. Engine exhaust, mixed with air, is pulled through the dryer bed by a variable speed blower to control exiting gas temperature above saturation and reduce wood moisture to 8 to 15% (wet basis). The 2.1 m (7 ft) diameter gasifier has a 2.4 m (8 ft) deep char bed below the ~0.3 m (1 ft) deep pyrolysis zone. The nominal dried wood and air flow rate into the gasifier are 816.4 kg (1800 lb) per hour and 0.189 sm^3/s (400 scfm) with gasifier temperatures about 982 to 649°C (1800 to 1200°F) from top to bottom. The synthetic gas (syngas) produced is about 0.52 sm^3/s (1100 scfm) with a higher heating value of about 6353 kJ/sm^3 (170 Btu/scf). Char is removed from the bottom of the gasifier through multiple, rotating "star" valves, collects in a discharge cone, and is removed through two screw conveyors to a transportable dumpster bin. The char is added to a local coal boiler. The syngas from the gasifier passes through 1) a cyclone, 2) a tube-in-shell (water) heat exchanger, 3) a coalescing liquid separator for tar and



p = gas pressure in psig; F = degrees Fahrenheit; HX = heat exchanger
Figure 1. CLEW process diagram.

water removal to a decanter, 4) impingement filters, 5) a multistage blower, 6) the second stage of a heat exchanger and liquid separator to compensate for heat added by the blower and to reach engine intake temperatures, and 7) a flare to the atmosphere, and/or the reciprocating engine. The Waukesha L7042 GSI turbo-charged engine and generator is rated at 1 MW electricity on natural gas and up to 700 kW with syngas from wood.

Continuous gas analyzers measure carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), hydrogen (H_2), and oxygen (O_2) in the syngas. Wood, tar, water, particulates, and exhaust gas from the dryer are sampled periodically for analysis. Data acquisition and control of most operations are accomplished by Wonderware© logic running on a Pentium 90 PC and by GE Fanuc 90/30 Programmable Logic Controllers (PLCs). Automated control coordinates gasifier air, fuel feed, intermittent star valves and augers operation, and water drainage.

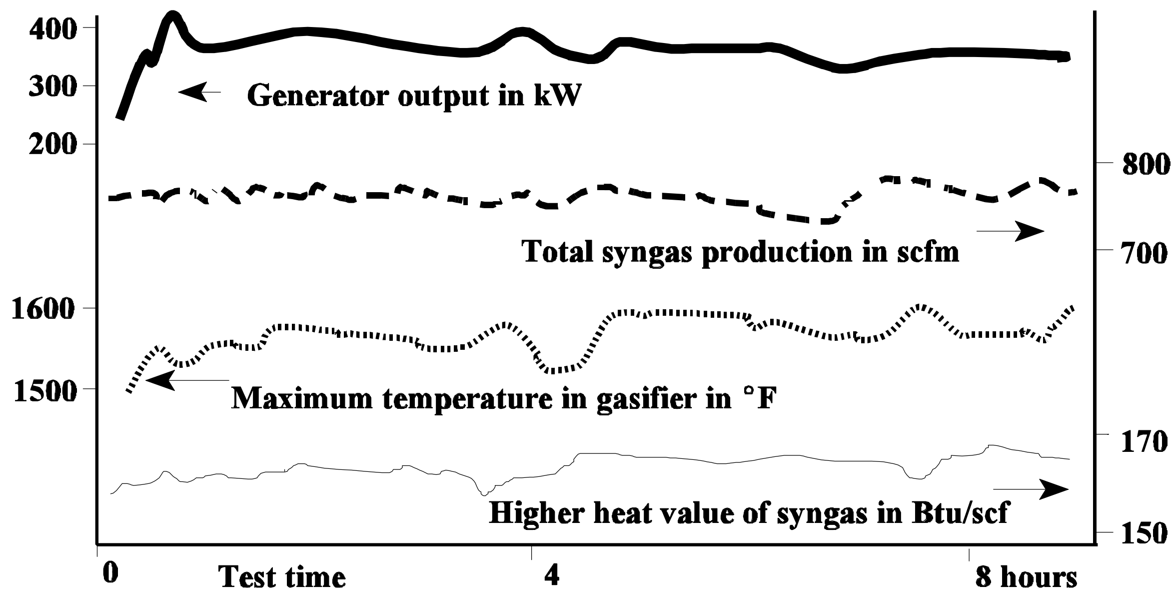
All components of the CLEW system are operational, and electric power is being generated for the Base grid. More than 50 test operations have been completed (see Table 2). Typical operating periods of 8 to 32 hours allow working within personnel constraints and the need to assess performance and add improvements. A baseline of performance under present limitations has been established (see Table 3). Figure 2 shows the stability that can be obtained over typical short-term operations.

Table 2
Test and demonstration summary

Test type (# completed)	Results
Drying tests (10)	consistent bulk drying of hogged wood (25 to 40% moisture, wet basis) to 10 to 13% moisture with exhaust/air at ~ 193°C (380°F); ~ 4 hour residence time; <50 ppm VOC
Pellet fuel, gas flared (10)	high fuel cost; gasifier Δp 3x hogged fuel; fine char; 6727+ kJ/sm^3 (180 Btu/scf) syngas; ~10% moist
Hogged wood gasified and flared (13)	5979+ kJ/sm^3 (160 Btu/scf) gas; 10 to 25% moist vs. 10% for pellets; tests to 30 hours; fuel prep debugged
Propane and engine (8)	engine shakedown; test timing effects; operation limited by gas supply to 400 kW; smooth
Hogged wood syngas and engine (16)	easy start; smooth throttling, no detonation; gas supply limited output and efficiency; 1.05> power factor >0.96; some excess moisture in gas

Table 3
Plant performance during hogged wood fuel and engine tests

Plant, gen-set efficiency	presently: 13, 19%; upon completion: 18, 26%
Syngas composition	18% CO, 19% H_2, 14% CO_2, 5% CH_4, and 44% N_2
Dirt/dust & VOC from drying	dust <3% of fuel mass & VOC < 50 ppm of stack gas
Conveyor, motor maintenance	about 45 min per day
Tar: gasifier outlet; engine inlet	<1000 ppm; <60 ppm; typical 0.3 to 1.5 μm particle size
Engine timing on syngas	20° BTDC (before top dead center); smooth start and operation; no detonation
Cyclone efficiency estimate	85% for > 2μm; fines recovered <0.5% of fuel
Water from separators	toxicity low-negative; < 1% TOC (total organic carbon); approved drain to sewer



1 scfm = 0.00047 sm^3/s; °F = 9/5 °C + 32; 1 Btu/scf = 37.4 kJ/sm^3

Figure 2. Performance parameters over typical test period.

3. PROBLEMS, SOLUTIONS, AND FUTURE PLANS

Maximum gasifier temperatures are closer to 816°C (1500°F) than the originally projected 982°C (1800°F) because of pressure losses and blower limitations. The engine-generator output is below 500 kW for the same reasons. It is impossible to keep at least 1.52 m (5 ft) of the char bed above 649°C (1200°F) to provide cracking of tar.

The design and installation delivered for RTI operation was based on past experimental plants by TTi and a subcontracting firm, Mech-Chem Assoc., and proved to be functional in most cases. However, operational results and experience have pointed out a number of corrections that have been or will be made, especially in future commercial installations. The components identified to be changed or eliminated are shown shaded in Figure 1.

No insurmountable problems have been found, and indeed most solutions will result in considerably lower installation and operating costs. These are summarized in Table 4. All solutions in Table 4 will be implemented in either the existing plant or the next design and installation. It is additionally planned to assess:

- wood drying influence on char bed tar reduction, gasifier efficiency, and gas quality,
- tar formation (mass, distillation fractions) and effects on engine maintenance,
- the option of converting a diesel engine to spark operation with syngas, and
- larger “chunkwood” fuel effects on pressure loss, gas quality, and fuel preparation.

While the project emphasized low equipment investment, the improvements described can further reduce installed cost for a CLEW plant to about $760/kW.

Table 4
Demonstrated problems and solutions for commercial application

Unit Operation Problems	Solutions
Gasifier: Channeling in bed (Figure 3); air leakage (e.g., behind interior wall refractory) causing deep bed combustion; excessive char in reactor for adequate tar cracking at high temperatures.	Improve rake design over center of fuel bed (Figure 4); add access holes in top of gasifier; tighten star valve seals; eliminate interior wall insulation below pyrolysis zone; reduce bed diameter and depth.
Fuel handling and drying: Excessive mechanical complexity and maintenance.	Eliminate walking floor trailers and table feeder -- place tub grinder by wood dryer and feed directly into dryer; replace all slat conveyors with belt conveyors.
Tube and shell heat exchangers; filters; dampers: Tar blockage, some soot blockage -- excessive pressure losses; tar condensation on water cooled tubes (Figure 5); sticking seals.	Replace shell-side water cooling and cooling tower with air cooling and fans; reduce number of impact filter plates; install simple dampers with metal-to-metal seals; replace cyclone with high-efficiency dry scrubber; improve access for cleanout.
Separators/decanter: Inadequate separation of tar, oil, and water; pumping problems; poor level detection.	Use gravity feed only; replace radio or other level detectors with mechanical units; replace decanter with active separation or chemical treatment for flocculation/settling.
Char screw conveyors; rotary and plug valves: Blockage by char, slag, and scrap metal.	Keep only one char conveyor and no active valves; add wet bottom for vacuum seal; improve calibration and detector of char level and removal in gasifier cone; add more magnets.
Six-stage main blower: Excessive pressure losses; overpowered; seizing from tar solidification.	Use larger-size wood fuel to reduce gasifier pressure loss; replace with a single-stage blower (like the start-up blower, which showed no seizing problems and is more efficient).
Engine: Insufficient gas to engine to permit higher efficiency and power output; excess water in gas; inadequate air/fuel ratio control (Figure 6); possible long-term tar contamination.	Increase blower flow by reducing pressure losses and replacing blower; increase turbo capacity for difference between natural gas and syngas mass-rate/power ratio; eliminate water spray for gas cooling or cleaning; add dual, low-area, single-stage, quick-change fabric filters; add air control valve.

(Continued)

Table 4 (Continued)

Unit Operation Problems	Solutions
Instrumentation, controls, cabling: Fouling and failure of transducers; maintenance for too many logic components; wiring exposure to environment; complex programming protocols.	Eliminate distributed PLCs; put all wiring in closed conduit; eliminate electromagnetic level detectors; place all sensors within 1 ft of sample location; install solid-state pressure transducers; install simpler operating system for process control and data.
General: Excessive equipment and installation costs; overweight materials; some equipment difficult to access because of high elevations; building enclosure restricts access, ventilation, and convective cooling; under-utilized byproducts.	Station engine by dryer for short flow path; eliminate double wall on cyclone; install lighter piping, vessels, flanges, structure (e.g., 5 vs. 40 gauge); place roof cover only for maintenance and sampling stations; place all equipment on ground; install system for steam activation of char; burn tar for process heat; recover heat from hot gas pipes.

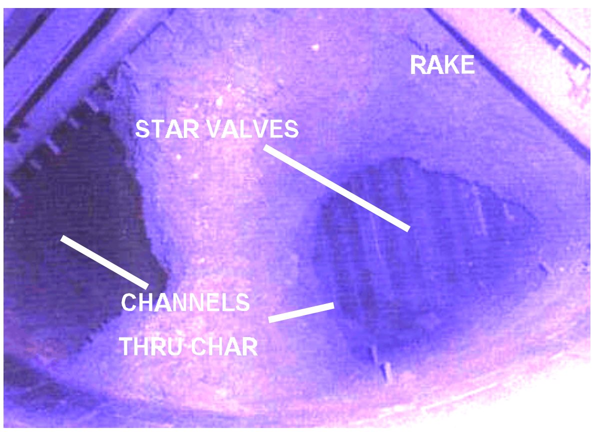


Figure 3. Emptied gasifier -- channels reduce gas quality, tar cracking, cause hot spots.

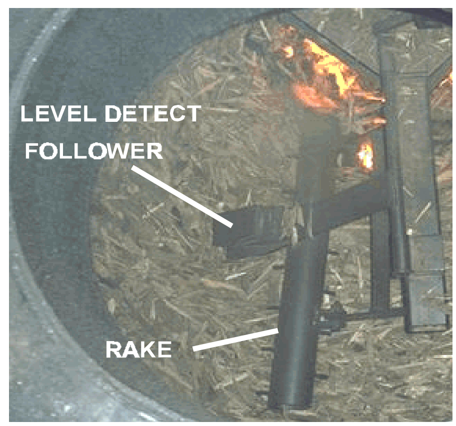


Figure 4. Gasifier bed leveling.

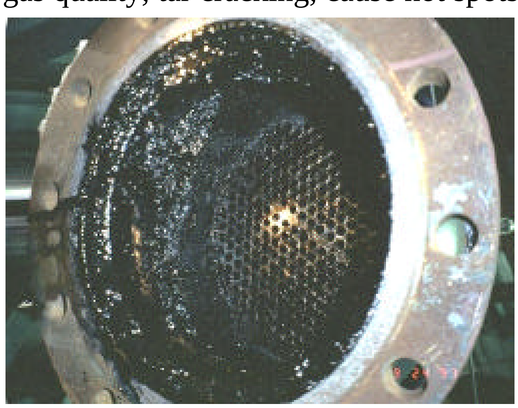


Figure 5. Tar condensed in water-cooled heat exchanger.

Figure 6. Engine: air/fuel mixed before turbo.