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INVESTIGATION OF THE VIABILITY AND COST EFFECTIVENESS
OF SOLID FUEL GASIFIERS CLOSE COUPLED
TO INTERNAL COMBUSTION ENGINES FOR 200 KWe POWER GENERATION

TECHNICAL PROGRESS REPORT NO. 9

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I. SUMMARY AND CONCLUSIONS

The viability and cost effectiveness of a 200 KWe engine generator unit fueled by a direct coupled, solid fuel gasifier was studied. Recent literature describing gasifier technology was obtained and personal visits were made to test facility sites and engine manufacturing plants to discuss the subject with researchers and engineers. Two prototype units were inspected, one of which was seen in partial operation. This report presents a brief discussion of fuel and gasifier technology, gas treatment (clean up) for engine use, engine use technology, other uses for gasifiers, the viability of close coupled units, and an estimate of cost effectiveness.

The viability of a gasifier-engine-generator unit should be determined by the following considerations:

1. The unit must be cost effective.
2. The unit must be compact in size and, in some instances, portable.
3. The unit must be environmentally acceptable complying with air and water pollution regulations.
4. The unit must be within present technology limits for construction, service, and operation.
5. The unit must provide some incentive for the owner/operator to make the required investment for capital and operating costs.

Present small experimental gasifier systems perform as expected and have served to demonstrate the technology. Typically they operate with fuel species which are present and collected on the site of a processing

plant. Not all gasifiers are used to generate gas for use in internal combustion engines. However, a few plants have put systems together to demonstrate this concept.

Based on the review of current technology for close coupled gasifier-engine-generator systems, it appears that developmental efforts are needed before such systems could be considered viable:

1. Fuel species which are dispersed in harvesting sites (including both agricultural and forest residues) are not presently viable fuel alternatives due to the high cost of collection, densification, and transportation. Methods of reducing these costs must be found before such fuels will be considered economically attractive.
2. Gasifier operating parameters are not well documented in the open literature and present designs are largely proprietary. This limits the ability of engineers and designers to promote use of the systems. It is important that the designs and operating parameters of the systems be well documented and that the data be placed in the context of fuel to air ratios, gas production rates, char, tar and ash production rates, and resultant gas composition.
3. There are a variety of alternatives for gas cleanup systems. These alternatives necessarily have compromise solutions to the goal of reasonable low costs and high gas purity (free from water, condensed tars, and particulate matter). Developmental efforts in the area of gas cleanup are warranted to reduce their size and cost and improve their performance.

4. Engine use technology for low BTU gas is not well documented for high speed, turbocharged diesel engines. Full load operation at near stoichiometric air to fuel ratios may not be obtainable in all engine designs. Further efforts in this area will improve the understanding of the limits of use of low BTU gas in such engines. Closely related to this technology is the use of gas turbines fueled by low BTU gas (in the range of 150 BTU/ft³). They may be a viable alternative to diesel engines but their successful operation is not presently documented. A limiting factor for both diesel and turbine engines may be the fuel metering device for the low BTU gas. Such metering systems are not presently available as off-the-shelf items and developmental efforts appear to be warranted.

The gasifier-engine-generator system in the 200 KWe size will be cost effective at the present time if the following conditions are met:

1. The solid fuel must be available and collected at the gasifier site at relatively low cost.
2. The cost of utility furnished electricity must be higher on a ¢/KWH basis than the cost of electricity produced by the gasifier-engine-generator unit, taking into consideration costs for depreciation, interest on capital, operating and maintenance expenses. With current electricity rates in specific areas (e.g., the Pacific Northwest), use of a gasifier-engine-generator system may never prove cost effective.

3. There may be installations where the waste heat from the unit or a part of the low BTU gas generated may be used to offset the costs of the system.

II. HISTORIC BACKGROUND

The destructive distillation of cellulosic materials is an old art. The literature (1) describing this process was prolific in the early 1920's. A revival of the art, applied to motor vehicles, occurred in the early 1940's (2). Recent literature has refined the process to make use of waste materials (4,5,6,7). Destructive distillation may be divided into two classifications.

1. Pyrolysis

Pyrolysis is thermal processing in the absence of air where endothermic heat energy is supplied from an external source. Applied to wood, the off-gas is cooled and the volatile liquid organic materials (tars) are condensed and refined to methanol, acetic acid, etc. Formerly the non-condensable gases were usually fired under the retort or in steam generating facilities. The heating value of the gas is typically 300 BTU/ft³. The char remaining after the pyrolysis is complete is nearly pure carbon.

Applied to coal, the off-gas is cooled and the liquid organic materials are condensed and refined to aromatic hydrocarbons. The non-condensable gases were distributed for domestic and industrial use as energy sources. The heating value of these gases is typically 600 BTU/ft³. The coke remaining was principally used for metallurgical purposes.

2. Gasification

Gasification is thermal processing using oxidation-reduction reactions. Endothermic heat energy for the process comes from the partial

oxidation of the material being processed. The air to fuel ratio determines the gas composition. Steam can be admitted with the air to the incandescent zone in the reactor to bring about dissociation and reduction reactions. The flow of air through the system can be either co-current or counter-current and the direction of flow will determine the yield of tar and char. It is theoretically possible to yield minute amounts of tar and char, and, of course, this is desirable if the purpose of the system is to produce only low BTU gas.

Applied to wood or coal without steam injection, the heating value of the off-gas would be approximately 150 BTU/ft³. Applied to coal with steam injection, the heating value of the off-gas would be approximately 300 BTU/ft³.

3. Vehicle Engine Use

Solid fuel gasifiers for motor vehicles were developed and used extensively in central and northern Europe during World War II due to the shortage of motor fuel. These units developed from 30 to 100 HP and weighed from 1000 to 2200 pounds. Skov and Papworth (2) have published an excellent text on the Pegasus Unit (Petroleum/Gasoline Substitute Systems) in which they provide substantial details of construction. About a dozen such units are shown schematically including details of the elaborate dust filtering and gas cooling apparatus associated with each system. These units worked but were "gleefully thrown in the trash heap" when petroleum was again available (2).

III. FUEL CONSIDERED

1. Material Species

If the motivation for perfecting a gasifier-engine-generator system is to use collected, on-site fuel, then the list of potential species is narrowed to the following:

1. Crop Residue: Pits, hulls, and cobs
2. Wood Residue: Bark and mill wastes

The above materials are concentrated at plant sites and may present a waste disposal problem. Their cost has already been charged to the plant operating cost for raw materials and production.

The literature reports high costs for collecting and transporting potential fuel materials which are normally left in the field (e.g. straw and forest slash) (11,12). Estimates of \$5 to \$30 per ton for collection and transportation result in the conclusion that such materials are not economically attractive as candidates for gasification at the present time.

The fuels listed above are substantially the same in their chemical makeup but may have varying ash content. The moisture content and their physical characteristics of size and shape may also vary widely. Because low moisture content and uniformity of fuel size is desirable for operation of gasifiers, fuel preparation systems may be warranted for specific fuel species. (See discussion below.)

2. Sizing

The size range and distribution of the raw feed stock is critical in gasifier systems. Most gasifiers are "gravity" fed from the

top through a rotary air lock or charging hopper. "Choking" of the feed system and/or "bridging" of the fuel in the gasifier reaction chamber must be avoided for continuous, smooth operation. These problems can be limited by carefully controlling the size of the raw feed stock. A system of hogs and screens can be used to avoid excessive amounts of fines and/or large pieces.

3. Densifying

In addition to the uniform fuel material size requirement for conveyor loaded, gravity fed gasifiers, the correct bulk density of the fuel material is important. Fluffy material with low bulk density would tend to "float" and cause handling problems when using conveyors as well as kinetic problems inside the gasifier. Limited gasifier operating information has shown that fuel materials such as straw should be compressed into cubes or briquettes for successful handling and gasifier operation (13). Also, gas production rates per unit weight of fuel material are increased as bulk density is increased (14).

4. Predrying

Variable fuel moisture has two negative effects on the operation of a close coupled gasifier-engine-generator system. First, variations in moisture level will make it difficult to control the operation of the gasifier and provide uniform off gas characteristics. Second, the presence of water vapor in the off gas reduces the effective BTU content of the gas and limits the fuel input to the engine. Condensation of water vapor is possible in an off gas cooling system and should be given high priority in design and operation of the system.

An obvious method of avoiding these difficulties is to predry the raw material feed stock before it enters the gasifier. A dryer system may incorporate the use of waste heat from the engine exhaust system and/or the use of waste heat from the off-gas condensor. The dryer system should be operated to provide a uniform, low moisture level content in the feed stock.

IV. GASIFIER TECHNOLOGY

As noted in Section II, Historical Background, destructive distillation may be considered in two classes: pyrolysis and gasification. Based on experience gained with pyrolysis it appears that this technology would not be suitable for use with close coupled engine-generator units. Pyrolysis systems generate substantial quantities of both carbon char and tar. Unless use can be found for these byproducts, they constitute a significant waste disposal problem. The carbon char must be quenched and cooled to avoid a fire hazard. It is a low density material which is "dirty" to handle and presents a dust problem. Briquetting or bagging of the char would probably be required, thus adding additional costs to the system for capital, operation, and maintenance costs. The tars generated in pyrolysis systems are viscous, odorous, chemically unstable, and significant in volume. As with the carbon char, they must be collected and disposed of in a satisfactory manner.

A positive advantage of pyrolysis systems is that the gas produced has roughly twice the BTU content per cubic foot as the gas produced in gasification systems. Further, it may be possible to recycle

the collected tar back to the pyrolysis reaction chamber to heat the retort (6).

1. Basic Gasifier Design Considerations - Counter Current, Co-Current Flow

Solid fuel gasifier systems can be designed to operate with the flow of gas in the same direction as the flow of solid fuel (co-current) or with the flow of gas in the opposite direction as the flow of solid fuel (counter-current). In counter-current systems, the fuel is admitted at the top of the reaction chamber and flows downward by gravity. Air is admitted under a fixed grate at the bottom of the reaction chamber and move upward through the fuel. As the air enters, it is subjected to the highest temperature zone of the reactor immediately, and undergoes the oxidation-reduction reaction with the fixed carbon portion of the fuel. This reaction is exothermic and provides the heat required for the endothermic distillation and drying processes taking place in the upper levels of the reactor.

The general characteristics of the off-gas from counter-current gasifiers are:

1. High tar content
2. High moisture content
3. Low entrained particulate concentrations
4. Low exit temperatures (typically 300 °F)

In co-current flow gasifier systems, both air and fuel move downward through the reactor. Air enters the system at the coldest point in the reactor and moves through the fuel bed. The point of

highest temperature is still located near the grate at the bottom of the reactor and that is the point where the exit gas leaves the system. The general characteristics of the off-gas are:

1. Low tar content
2. Low moisture levels
3. High entrained particulate concentrations
4. High exit temperature (typically 1000 °F)

2. Air Preheating

It would be desirable for both counter-current and co-current systems to use preheated air in the reactor. However, this is particularly important in co-current systems where air enters the reactor at the coldest point. Off-gas from the reactor must be cooled to condense any moisture and tar present in the gas. Since a heat exchanger is required for this purpose, it can be used to preheat the incoming gases to the reactor.

3. Ash And Char Removal

Wood fuels typically contain 1% inorganic ash in the dry fuel. This ash enters with the wood feed and must be removed from the reactor on a regular basis. For the example case of a 200 KWe gasifier-engine-generator system, the feed rate of dry wood will be approximately 6.6 dry tons per day. The inorganic ash that must be removed from the system will thus amount to approximately 132 lbs per day.

Under typical operation one would also expect to find some

carbon char in the ash. However, even if the total ash weight were doubled (264 lbs/day), its removal from the system does not present any major limitations in the design or operation of the system.

If pyrolysis units are considered (rather than gasifiers), then the problem of ash removal becomes more significant. The fixed carbon char generated in pyrolysis units may constitute 12% of the fuel fed to the reaction chamber. Using the example again of a 200 KWe system requiring 6.6 tons per day of dry fuel, 12% of the fuel is approximately 1,584 lbs per day of char. Carbon char has a typical density of 9.4 lbs/ft³. Thus, the volume of char that must be removed and handled would be approximately 170 ft³ per day. If the material is stored in 55 gallon drums, it will require 24 drums per day or one per hour.

4. Gas Composition

The composition of the off-gas from a gasifier is dependent upon the following variables:

1. Specie of material used for feed stock
2. The incoming moisture content of the feed stock
3. The air-to-fuel ratio used in the gasifier
4. The temperature at the grate in the reaction chamber

The temperature and the composition of the off-gas will determine the heating value per cubic foot of gas delivered to the engine.

The combustible components of the off-gas are principally carbon monoxide (varying from 20% to 30% by volume), hydrogen (varying from 10% to 20% by volume), methane (varying from 1% to 2% by volume)

and minor amounts of ethane (typically less than 1% by volume).

The non-combustable off-gas components include carbon dioxide (varying from 5% to 15% by volume) and nitrogen (varying from 45% to 50% by volume).

Skov and Papworth (2) show variations in off-gas composition in their Table 12, page 89. The British Columbia Research Study (3) lists the variations of off-gas composition as a function of the air-to-fuel ratios in the reactor. The lowest and highest air-to-fuel ratios in their study produced gases with the following characteristics:

	Lowest Air-To-Fuel Ratio = 1.9 (by wt.)	Highest Air-To-Fuel Ratio = 3.5 (by wt.)
	Percent Volume (Dry Basis)	Percent Volume (Dry Basis)
Hydrogen	14.9	10.2
Oxygen	0.0	0.0
Nitrogen	47.2	63.3
Carbon Monoxide	26.6	17.2
Methane	1.4	1.1
Carbon Dioxide	9.5	7.8
Other	<u>0.4</u>	<u>0.4</u>
	100.0	100.0
HHV BTU/SDCF	155	106

Figure I shows the higher heating value (HHV) calculated as a function of the hydrogen and carbon monoxide content of the off-gases. Note the significant contribution to the HHV from minor amounts of methane and ethane constituents.

Figure I: Low BTU Gas HHV vs Composition

Lewis and Ablow (6) have estimated the final gas composition and higher heating value from an indirectly heated, rotary kiln pyrolyzer as a function of the pyrolysis temperature. Their range of estimates for low and high temperatures are shown below:

	Low Temperature (800 °F)	High Temperature (1700 °F)
	Percent By Vol.	Percent By Vol.
Carbon Monoxide	3	42
Hydrogen	10	56
Carbon Dioxide	37	-
Methane	50	2
	<u>100</u>	<u>100</u>
Higher Heating Value (BTU) SDCF	550	330

The high percentage of methane from the low temperature operation would be an advantage to engine operation from both energy and volumetric considerations.

5. Gas Production Regulation

Gas production in gasifier systems is controlled by the air-to-fuel ratio in the reactor. As the ratio decreases the rate of production increases. The time response of gasifiers is relatively rapid in that the gasification reaction responds quickly to changes in air-to-fuel ratios. Changing the rate of fuel feed to the gasifier does not have a significant impact on the rate of gas production because the reaction rate is not limited by the amount of fuel present in the reactor.

In pyrolysis systems, the rate gas production is controlled by the temperature and the heat input rate to the reactor. As the reactor temperature increases, the gas production rate increases. Pyrolysis reaction chambers (retorts) have a significant amount of "thermal inertia" which results in relatively long time response to changes in temperature and, therefore, in rate of gas production. As is the case with gasifiers, the rate of gas production in pyrolysis systems cannot be well controlled by controlling the fuel feed rate.

V. GAS CLEANUP FOR INTERNAL COMBUSTION ENGINE USE

In order to properly operate an internal combustion engine, the gases used in the engine must be cleaned. In the case of gas produced in gasifier or pyrolyzer systems, this requires removal of entrained particulate matter, condensable tars, and water. Further, in order to maximize the output from the engine, the gases must be cooled to remove sensible heat energy. The degree of gas cleanup and cooling may vary substantially according to the system used and inevitably results in engineering compromises to balance cost and efficiency.

1. Particulate Removal

All references to past and present gas producing systems place great emphasis on the removal of particulate matter. The gas should be as free from particulate matter as the combustion air supplied to the engine. All engine manufacturers have standards for air filtration and employ various filtering mediums to meet the needs of the particular operating environment of the engine.

Present gas cleaning systems used with gasifiers and pyrolyzers employ multi-stage particulate removal schemes. The first is typically an inertial separator which is effective for removal of large particles (above 5 microns). Inertial separators have the additional characteristics of being able to handle high temperature gases with a small pressure drop through the system. They can be operated either as push-through or pull-through systems. If the gas temperatures in inertial separators are high enough to avoid condensation of the entrained condensable tars, then plugging will not result due to the tar. Cyclone (inertial) separators are readily available in a wide variety of sizes and configurations.

The second stage of gas cleaning is to remove the small particles which passed through the first stage inertial separator system. Removal of these fine particles can be accomplished with cloth and/or paper filter media, however, such media have limits on their operating temperatures. (8) Maximum operating temperatures are typically in the neighborhood of 450 °F. This requires that the gas stream be cooled prior to entering the second stage cleaning. Note, however, that if the gas stream is cooled to the point where tars can condense, the condensed tars will plug the filter media and render it inoperative. Thus, operating temperatures in second stage filter systems may be critical. The potential difficulties of tar condensation can be avoided if the off-gas is cooled sufficiently to bring about complete condensation of the water and tar prior to secondary stages of gas cleanup.

2. Water and Tar Removal

An engine should be able to "digest" water vapor in the fuel

gas with no significant ill effects. The limitation in the operation of engines is that water vapor occupies volume in the fuel gas. The energy per cubic foot of the gas will decrease as the water content increases. Moisture content in the off-gas of a gasifier may be 40% of the total, and, thus, its presence reduces the available energy in the off-gas significantly.

The optimum method of dealing with entrained moisture in the off-gas is to cool the gas below the dew point of the water vapor. A heat exchange system can accomplish this and remove the condensed water from the gas stream.

It is not clear at this writing how much tar can be entrained in the gas stream without detriment to the engine. If entrained tars condense inside the engine, problems associated with sticking of rings and valves might occur. It is desirable to condense the entrained tars prior to their introduction to the engine, and, as mentioned previously, prior to their introduction to the second stage filter system.

3. Sensible Heat Removal

The temperature of the off-gas at the exit of a gasifier or pyrolyzer system could range from 500 °F to 1000 °F depending on the process. It is desirable to maintain the initial temperature of this gas during the first stage of particulate removal in the inertial separators. As noted in the previous discussion, cooling is then desirable for water and tar removal and to avoid temperature limits in second stage filtering of particulate matter.

Cooling is also important to increase the density of the gas entering the engine. To achieve 150 BTU/SCF of fuel gas, the gas must be cooled to 60 °F (at a pressure of 30.00 inches of Hg). Note: This assumes that the gas composition is typical of that found in co-current gasifier systems. It also assumes that the gas is void of water vapor. Figure II shows the effect of increase of gas temperature of the dry fuel gas on its higher heating value and the percent of rated load that the engine will produce.

Removal of the sensible heat from the off-gas stream can be accomplished with water cooled condenser systems or air cooled condenser systems. If cooling water is available at the plant site, it can be used in a cooler-condenser to reduce the fuel gas temperature to approximately the same temperature as the water. This has the advantage of removing most of the tar from the fuel gas, increasing fuel gas density to the desired level, and removing the water vapor content of the gas.

If cooling water is not available for this purpose, then an air cooled condenser must be used. These units are large by comparison to water cooled condensers and, further, require a fan system to move the cooling air through the heat exchanger system. The heat transfer surface for an air cooled system is approximately 100 times that required for water cooled systems. The final temperature of the fuel gas leaving an air cooled condenser is dependent upon the ambient air temperature.

The size and effectiveness of an air cooled condenser result from engineering compromises to balance cost, size, and results. It should be pointed out that if the low BTU fuel gas is to be used for direct combustion rather than in an engine, condensation cooling and

Figure II: Change of HHV of Dry Gas with Temperature
% Rated Load Change with Temperature

second stage particle removal systems are not required.

VI. ENGINE USE TECHNOLOGY

Once the fuel gas is generated, cleaned, and cooled, it is ready for use in an internal combustion engine or in a turbine engine. However, even at this point there are potential problems associated with metering the fuel in response to changes in engine load, reduction in the rated output of the engine, and re-tuning of injection systems and/or spark timing in order to optimize operation.

1. Natural Gas Spark-Ignition Engines

For natural gas fueled spark ignition engines, present practice is to pipe the gas to a gas regulator which meters the gas in proportion to the air flow in a throttled engine. This is done at a minimum pressure of 2 psig for naturally aspirated engines and 12 psig for turbocharged engines where the fuel is added downstream of the aftercooler.(9)

Natural gas has a lower heating value of approximately 900 BTU/SDCF. Thus the flow rate of fuel gas with a lower heating value of 146 BTU/SDCF would have to be at least 6 times that of natural gas to provide the same energy input.

The maximum power of a naturally aspirated engine is based on consuming all of the oxygen than can enter the engine. The large quantity of fuel gas (which is about 60% inert nitrogen and carbon dioxide) displaces a significant quantity of air and, thus, reduces the available oxygen. Therefore, the engine must be derated. A turbocharged engine would suffer the same derating unless the air and fuel were compressed to a higher pressure prior to entering the engine. There is a limit to the

boost pressure that can be tolerated without encountering detonation, though this may be compensated for by lowering the compression ratio and accepting some loss of efficiency and power. It is presumed that pressures up to 12 psig could be supplied by the gasifier air pump if it were installed after the gas cleanup system. This would make both the gasifier and the gas cleanup systems operate as "pull-through" systems. The design is desirable provided that the pressure drop through the complete system was not too large.

A. Derating

For a naturally aspirated engine, it may be shown that the lower heating value per cubic foot of a chemically correct mixture of air and natural gas is about 87 BTU/SCF.(9) For fuel gas with a lower heating value of 146 BTU/SCF, the lower heating value of the chemically correct mixture of air and fuel gas is about 72 BTU/SCF. Therefore, an engine using fuel gas would be derated approximately 17%. Since there is a higher volume of fuel gas required, a special "high volume fuel flow gas mixer" (carburetor) would be required. These are not presently available as off-the-shelf items.

For a turbocharged engine, the air boost pressure may require an increase from 7 psig to 10.5 psig. It is probable that different compressor systems (turbochargers) than those currently used would have to be supplied.

B. Re-tuning

Carbon monoxide and hydrogen have different flame speeds than natural gas. Thus a change to fuel gas would require changes in the

ignition timing so that the combustion process produces maximum pressure in the cylinder just after the piston has passed top dead center. Close attention must also be paid to the aftercooled temperature. Each engine turbocharger combination would have to be subjected to experimentation to determine the correct timing in order to prevent detonation and still produce maximum power.

C. Boot Strap Start-up

If the gasifier-engine-generator system is not connected to an outside utility electricity supply or to a source of natural gas, then an auxiliary fuel tank or a low BTU gas storage tank must be provided to start the engine while the gasifier is being brought up to operating temperature. A storage tank for low BTU gas would require either a large compressor coupled with a small tank or a small compressor coupled with a large tank. Either option is not very viable. However, propane stored as a liquid has an history of being an excellent engine fuel. It could be used for engine startup and then shut off when fuel gas is available from the gasifier system.

2. Diesel Engines

There is some historical background for the operation of dual-fuel diesel engines. The most recent literature dates to the 1940's where large diesel engines were operated with manufactured gases containing carbon monoxide and hydrogen (15). During operation the diesel injection systems were used at about 10% of their rated capacity. The injected fuel, called a pilot charge, served as a multi-ignition source for the gaseous fuel.

A. Derating

For diesel engines using fuel gas, the fuel gas flow rate and pressure would likely be controlled by a gas regulator. The controlled gas flow would enter an intake manifold similar to a natural gas, spark ignition engine system. However, combustion air is not throttled in a diesel engine. Therefore, the engine would still be operating on a variable air-to-fuel ratio basis.

To control exhaust gas pollutant emissions, diesel engines are operated with a minimum air-to-fuel ratio of about 20 to 25 (lbs/lb). This means that there is significant "excess air" available in typical operation to meet the oxygen requirements for combustion of the fuel gas. As a result, naturally aspirated diesel engines would be derated less than naturally aspirated natural gas engines. Turbocharged diesel engines with an adjusted air boost may not be derated at all when fuel gas is used. The Bmep is the limiting factor though there is some question as to whether fuels with high hydrogen content can be combusted at stoichiometric air-to-fuel ratios without detonation.

B. Re-tuning

The timing for the pilot charge diesel injection may be different than the timing for full diesel injection. Thus, some adjustment may be required for optimal operation.

C. Boot Strap Start-up

Starting the diesel engine on diesel fuel when the gasifier is not producing gas and then switching over to dual fuel operation when

desired is within the limits of available technology. However, regulators for controlling the fuel gas to govern engine speed are not an off-the-shelf item.

3. Gas Turbines

There seems to be no fundamental reason for excluding the concept of utilizing low BTU fuel gas in a gas turbine. It is critically important, however, that the fuel gas be free from entrained particulate matter. Particulate matter passing through exhaust turbine blades would result in significant blade erosion. The relationship between particle concentration and the life of a diesel engine is roughly linear and inverse. The relationship between particule concentration and the life of a gas turbine is probably exponentially inverse. This is because the particles in a gas turbine have very high velocities and correspondingly high levels of kinetic energy.

A. Fuel Pressure

Industrial gas turbine compressor pressure ratios are about 5:1 and the absolute pressure in the burner is about 75 psia. The fuel gas must, therefore, be compressed separately from the air to a pressure greater than 75 psia. It has been estimated that the low BTU fuel gas compression process will require about 12% of the available power compared to 2% for natural gas. The fuel nozzles and the burner liner may require some re-design for optimum liner protection.

B. Derating

Piston engines are derated for use with fuel gas principally

because of the limit placed on the availability of oxygen for combustion. Gas turbines are not limited in this regard and would not be derated for this reason. However, as mentioned above, the fuel gas compression required for the gas turbine reduces the net power available from the unit. Turbine inlet temperature is the limiting operating parameter. The small amount of carbon atoms in the fuel gas makes it a reasonable fuel.

VII. OTHER USES FOR GASIFIER FUEL

If the broad concept of energy utilization is applied here, there may be preferred uses for low BTU fuel gas rather than for internal combustion engine fuel. For example, using the gas to fuel a burner for a dryer system or using it in a boiler to generate steam for process use has the following advantages:(4)

1. The sensible heat may be conserved and used productively
2. The tar and water do not need to be condensed. In fact, the tar would add to the energy liberated in the burner.
3. The level of particulate removal from the gas would not be as great as that required for engines and turbines. The concentration of particulate matter in the exhaust stack gas would control the level required for fuel gas cleanup.
4. Only the fuel nozzles and fuel regulators on existing burners would have to be modified to use the low BTU gas as a replacement for natural gas or oil.

VIII. VIABILITY

The dictionary defines viable as "capable of growing or developing". This definition applied to a small, solid fuel gasifier-engine-generator unit should be more specific and it is suggested that the following criteria be considered:

1. Requirements For Viability

1. The complete system must be cost effective.
 - A. It must not be capital intensive compared to alternatives.
 - B. It must not be labor intensive; a nearly automatic system is desirable.
 - C. It must be profitable to the owner/operator.
2. The complete system must be relatively compact and in some instances portable.
 - A. It should require a minimum of space.
 - B. It should be capable of being moved to the operating site, set up, and started with a minimum of time required.
 - C. If the unit is designed to be portable, it should not require utility connections for water, electricity, or natural gas.
3. The system must be environmentally acceptable, complying with air and water pollution regulations.
 - A. Engine exhaust should meet state and federal emission standards.
 - B. Fugitive emissions from the solid fuel storage and handling should comply with air pollutant regulations.

- C. Water discharge (if any) should meet all existing standards for water pollution, including standards on allowable temperature for waste water.
- D. Noise regulations must be met.
- E. Solid material disposal should be minimum for the location.
- 4. The complete system must be within the limits of present technology to construct, service, and operate.
 - A. The system should be available as a complete unit without the necessity of purchasing it piece by piece.
 - B. Replacements parts should be readily available.
 - C. The system should have a minimum of experimental or non-proven components.
 - D. The system should be capable of being operated by "non-specialist" personnel.
- 5. There must be an incentive for the owner/operator to invest in the system and operate it.
 - A. There must be some economic incentive.
 - B. The system must eliminate some present problem.
 - C. The system should serve to promote conservation of resources.

2. Present Technology

Present small experimental gasifiers do perform as expected in that they generate gas with specific fuels. Those fuel species that are concentrated in one location, such as on the site of a processing plant, have been used with modest success.

Some comments on the components of the systems are offered:

1. Fuel handling systems for sizing, loading, and storing the fuel are readily available. The exception to this lies in sizing equipment for agricultural straw which is not yet considered a fully developed technology.
2. Gasifier units have not been standardized in design. There are some units commercially available, however, it is felt that the state of the art is yet open to significant improvements for optimization. The device is not particularly complicated (compared to an internal combustion engine) but its reliability for long term use with variable fuels under variable loads is not yet established.
3. Cyclone separators for gas cleanup are readily available and proven technology. The same can be said for cooler-condensers and gas pumps which can be easily purchased from a wide variety of suppliers.
4. Secondary particulate removal systems using cloth or bag filters have not been applied widely to gasifier systems. Because of the potential limitations imposed by temperature in the fuel-gas and/or by condensation of tar and water in the filter, it is felt that developmental efforts are warranted in this area.
5. The controls for the gasifier process are available and adequate. Engine-generator sets and the related electrical switch gear are catalogue items but usually have long delivery

periods (e.g. 6 - 9 months after receipt of order).

6. Controls for regulating the flow of fuel gas are not presently available as off-the-shelf items and may require additional development before they are suitable for continuous use in the field.

3. Development Required

A. Fuel Collection And Preparation

Fuels which are presently collected at a plant site can be used for gasification if the density, moisture and size characteristics are within reasonable operating limits for present gasifier technology. Examples of such fuels are wood residue materials, pits and hulls at food processing plants, and peanut shells.

For wood fuels, there are significant quantities of material which are not presently collected and concentrated at plant sites. Materials such as forest slash (including down trees, limbs, and low grade species not used for production) are left in large volumes scattered over a broad area in our nation's forests. Present methods of collecting, chipping, and transporting this material are too costly to be justified with result that it is left in the forest where it is either burned or decays naturally. Developmental efforts to reduce these costs are needed before a significant increase in the use of this material will be realized. (10)

Agricultural residues such as straw are similarly hindered in their use due to the high cost of collecting, transporting, preparing, and handling. Use of straw is further hindered because straw contains a high percentage of silicon in the inorganic ash. The silicon fuses

at high temperatures and acts to plug systems with a glass-like material. Thus, it requires special design considerations for use, particularly if direct combustion is employed.

Unlike wood, straw residue is very low in density. Efforts to increase its density through baling and compaction have not been sufficiently successful to appreciably reduce costs for handling and transporting. The limitations of low density are increased after the straw has been dried and chopped.

Another major limitation in the use of straw residue (and most other agricultural crop residues) is that they are generated only once each year during a relatively short period of time, typically 6 - 8 weeks out of each year. To be used as a year-round energy resource requires that they be stored in appropriate (and potentially costly) storage facilities.

These limitations in the present use of agricultural wastes suggest a need for developmental efforts to reduce costs of collection, transportation, handling, preparation, and storage. With some significant reduction in the cost of present techniques, these fuels will too costly to justify their use as alternative energy resources in significant quantities.

B. Gasifier Technology

There is not sufficient technical information available in the present literature to establish the critical operating parameters for the various types of gasifiers. This is probably because the present small gasifier designs are proprietary. Air-to-fuel ratios, grate

temperatures, fuel moisture limits, and scale (size) effects are examples of critical design and operational data which is necessary to promote gasifier development and use. Since the final gas composition is dependent upon these variables, they should be clearly defined in terms of their effect on the final gas composition.

Grate design and ash handling equipment for high ash fuels should be advanced. Effects of combustion air preheat should also be evaluated. Recycling of the tar should be demonstrated and the optimal location for injection of the tar should be investigated (i.e., in cold zones or hot zones).

C. Gas Cleanup Technology

Cleanup of the low BTU fuel gas is the most pressing problem facing the development of gasifier-engine-generator systems. Two experimental gasifiers (of similar design and with co-current gas flow) have been operated and were hampered by tar condensation difficulties. First, the use of an air cooled condensor did not bring about complete condensation of the entrained tars. The remaining tars condensed in the gas pump when it shut down and cooled. This caused the pump to stick and made startup very difficult. Second, removal of fine particles in the secondary filter system using paper type filters resulted in very short filter life - approximately 3 hours. Third, the tar that was condensed in the air cooled condensor presented a waste disposal problem.

Obviously, these problems must be solved before the systems can be successfully operated for extended periods of time and before they will be attractive to prospective purchasers. Perhaps multiple stage condensers will help to remove the tar. Water scrubbers might be employed

but they are costly and complex systems taking into account the water cleanup problems which they generate. Water cooled condensor systems would be effective in reducing both tar and water vapor from the fuel gas and in raising the heating value per cubic foot of the fuel gas. But, they require a continuous supply of cool water and they act to condense the tar and water vapor together, thus creating a mixed stream of condensate which presents a waste disposal problem.

The sensible heat of the fuel gas is interrelated with the tar and water removal. Any cooling performed on the gas will help to solve both problems. Theoretically, the gas should be cooled to as low a temperature as the normal operating temperature of the gas regulator and fuel metering device on the engine.

Conservation of the heat energy from cooling the fuel gas stream will raise the efficiency of the system and may help to ease some of the operating difficulties.

D. Engine Use Technology

The developments needed to advance the viability of present day engines are associated with the fuel metering and external air compression systems. The fuel metering system must be developed so that it will respond to changing loads using low BTU gas. Developments are also needed in the dual fuel switch over system for standby and starting operations.

Additional data on operation with low BTU gas in turbocharged engines should be obtained. One company reports difficulty when operating between 70% and 100% of rated load. The exact gas composition affects the combustion characteristics of an engine and full load operation will

be near stoichiometric air-to-fuel ratios.

There is no recent literature reporting modern engine performance on low BTU gas. The amount and injection timing for the diesel pilot charge should be defined. The resultant exhaust emission characteristics must be documented.

The successful operation of gas turbines, in the 300 HP size, on low BTU fuel gas should be confirmed. The fuel compressor and burner can design suitability should be confirmed. The degree of particulate filtering of the fuel in relation to blade erosion must be determined. The exhaust emission characteristics must be known.

IX. COST EFFECTIVENESS

To provide an illustrative example of the cost effectiveness of a gasifier-engine-generation system, calculations were made to size and evaluate the cost of a 200 KWe system.

Table I shows the cost estimate of the gasifier-engine generator unit. The costs for the diesel electric set, trailer, gas compressor, cyclone, paper filter, and conveyors are catalogue prices including profit. The other costs are estimates based on experience at OSU with similar types of combustion equipment. It should be stated that no design work was accomplished and only the capacity and size of certain units were estimated. The total cost approaches \$100,000.

Table II, an excerpt from the monthly U. S. Bureau of Labor Statistics, shows the cost of electrical energy in several major cities and adjacent areas in the United States. The average cost is 5¢/kWh with New York and northeast New Jersey having the highest cost at 9.47¢/kWh and Seattle having the lowest cost at 1.47¢/kWh.

These costs are based on home owners monthly bills for 500 kW hours. The cost of industrial energy is presumed to be less but the geographic differentials should be similar.

Table III shows the estimated gross annual revenue and total annual costs, including a cost for fuel when operating 50 weeks, 7 days per week, with 24, 16 and 8 hours per day operation. Revenue was based on an 80 percent load factor with 5 and 10 cents per kilowatt hour rates. One of the largest cost items is for the operators' wages and it was assumed one man for one hour per shift could attend to the needs of an automatic unit.

Gasifier fuel rates were calculated assuming a 75 percent conversion efficiency, 90 percent generator efficiency, 25 percent brake thermal engine efficiency, higher heating value of 8500 Btu per dry pound, and 15% added fuel for auxiliary power. Calculations will show the rate to be 6.6 ton-per-day and 2300 ton-per-year. Fuel costs were based on 0, 5, 10 and 15 dollars per ton.

Table III also shows the estimated net annual profit and loss for a seven day per week operation. Note that when the energy is valued at 5¢/kWh, the profit disappears for 3 and 2 shift operation as fuel costs rise and is nonexistent for 1 shift. When the energy is valued at 10¢/kWh, a profit is shown for all cases except the 1 shift, 15 dollar per ton case.

Table IV shows estimated gross annual revenues and estimated costs based on only a five day week; all other assumptions are the same as the seven day estimate.

Table IV also shows the estimated net annual profit and loss from the five day week operation. Note that for the 5¢/kWh energy value, it is not profitable except perhaps in the 3 shift case with free fuel. For the

10¢/kWh energy value, the 3 and 2 shift operations are on the plus side for all fuel values, while the 1 shift operation is not profitable even with free fuel.

As shown in Figure III, it does not appear that any 5 day week operation would be cost-effective in any geographic area where the cost of utility electric energy is 5¢/kWh or lower. As shown in Figure IV, the 7 day week operation would yield about a 16 percent return on the investment for only free fuel and 24 hour operation when the electric cost is 5¢/kWh or lower.

Table V and Table VI, excerpted from the monthly Bureau of Labor Statistics, show the cost of No. 2 fuel oil and natural gas, respectively. The average cost of No. 2 fuel oil is 50 cents per gallon and the average cost of natural gas is \$3.53 per million Btu's.

In comparing the cost of alternate fuels for operating a 200 kW_e unit for 50 weeks, 7 days per week, and 24 hours per day at an 80 percent load factor (1.344 MW_eH) on alternate fuels, some assumptions must be made. On fuel oil, an engine brake specific fuel consumption of 0.4 pounds fuel per brake horsepower hour, 90 percent generator efficiency, 10 percent added fuel for auxiliary power, and fuel specific weight of 7 pounds per gallon were assumed. In addition, a brake thermal efficiency of 25 percent was assumed for natural gas operation.

Calculations will show, using the above fuel costs and assumptions, that fuel oil costs alone will be \$62,913 per year. If natural gas were used to fuel the engine, the cost for fuel would be \$79,128 per year. By comparison, the total operating costs of the system using solid fuel in a gasifier (including the distributed capital costs, service the debt, operation, maintenance, insurance, etc.) will be \$62,100 per year if the fuel cost is \$5/ton; \$73,600 if the fuel cost is \$10/ton.

TABLE 1

Cost Estimate of a 200 KWe Gasifier-Engine-Generator System

1. Diesel Electric Unit	\$24,000	
Dual Fuel Equipment	1,000	
Day Tank, Muffler, & Misc.	2,000	
Electric Switch Gear	1,000	
	Subtotal	\$28,000
2. Portable Alternate		
Flatbed Trailer (40')	8,500	
	Subtotal	8,500
3. Gas Compressor, 300 CFM @ 15 psig	8,000	
4. Cyclone Separator, 900 CFM	1,200	
5. Cloth or Paper Filter, 400 CFM	800	
6. Belt Conveyor, 20'	6,000	
7. Screw Conveyor, 12'	4,000	
8. Fuel Bin, 10' x 10' x 10'	3,000	
9. Gasifier, with Ash and Fuel Locks and Piping	10,000	
10. Controls	10,000	
11. Condensor	7,000	
12. Assembly	10,000	
	Subtotal	\$60,000
	Grand Total	\$96,500

TABLE II

Net Monthly Bills for Specified Kilowatt Hours of Electricity by Area

June 1978

Standard Metropolitan Statistical Areas	100 kWh		250 kWh		500 kWh		¢/kWh
	May 1978	June 1978	May 1978	June 1978	May 1978	June 1978	
Atlanta	6.18	6.23	10.61	10.72	19.25	19.47	3.89
Baltimore	8.26	8.88	17.09	18.63	28.63	31.71	6.34
Boston	7.61	7.64	15.27	15.37	25.43	25.62	5.12
Buffalo	8.50	8.34	15.25	14.89	24.35	23.66	4.73
Chicago-N.W. Indiana	6.62	6.62	14.25	14.23	26.20	26.17	5.23
Cincinnati	7.17	6.53	14.32	12.74	24.17	21.00	4.20
Cleveland	5.46	5.64	13.39	13.84	24.54	26.18	5.23
Dallas	6.45	6.70	12.70	13.10	22.00	22.63	4.53
Detroit	8.07	8.19	16.22	16.52	29.81	30.41	6.08
Honolulu	9.44	9.42	17.51	17.47	28.98	28.89	5.78
Houston	6.34	6.12	12.31	11.76	21.02	19.93	3.99
Kansas City	6.61	6.60	14.23	14.18	26.22	26.13	5.22
Los Angeles-Long Beach	7.08	7.01	13.97	13.80	24.78	24.45	4.89
Milwaukee	5.31	5.18	10.18	9.85	18.29	17.62	3.52
Minneapolis-St. Paul	6.80	7.26	12.98	14.11	23.27	25.53	5.11
N.York-NE New Jersey	11.17	11.96	23.58	25.23	43.59	47.37	9.47
Philadelphia	6.06	6.10	14.67	14.59	26.92	26.80	5.36
Pittsburgh	7.80	7.71	15.93	15.71	29.07	28.63	5.73
St. Louis	6.95	6.53	15.42	14.36	27.90	25.75	5.15
San Diego	5.85	5.85	11.97	11.97	25.73	25.73	5.15
San Francisco-Oakland	4.42	4.42	8.78	8.78	20.81	20.81	4.16
Seattle	-----	-----	4.76	4.85	7.22	7.36	1.47
Washington, D.C.	6.43	6.44	12.63	12.68	21.92	22.47	4.49

 $\bar{x} = 5.01$ $s = 1.41$

TABLE III
Estimated Annual Balance Sheet
for
50 Week, 7 Days per Week Operation

	Shift Hours	3 24	2 16	1 8
1. Gross Revenue @ 5¢/kwh		\$ 67,200	\$44,800	\$22,400
@ 10¢/kwh		134,400	89,600	44,800
2. Cost				
Depreciation, 10 yrs (100,000)		10,000	10,000	10,000
Interest, 10%		10,000	10,000	10,000
Insurance, Taxes, Misc., 2%		2,000	2,000	2,000
Front Loader Tractor, \$10/day		3,600	3,600	3,600
Overhaul and Maintenance		4,000	3,000	2,000
Operator Wages, \$20/hr		21,000	14,000	7,000
Subtotal		\$ 50,600	\$42,600	\$34,600
Fuel @ 0 \$/ton		0	0	0
5 \$/ton		11,500	7,667	3,833
10 \$/ton		23,000	15,333	7,667
15 \$/ton		34,500	23,000	11,500
Total W/Fuel @ 0 \$/ton		50,600	42,600	34,600
5 \$/ton		62,100	50,267	38,433
10 \$/ton		73,600	57,933	42,267
15 \$/ton		85,100	65,600	46,100
3. Profit and Loss				
Revenue @ 5¢/kwh	Fuel			
	0 \$/ton	16,600	2,200	(12,200)
	5	5,100	(5,467)	
	10	(6,400)		
	15			
Revenue @ 10¢/kwh, 0 \$/ton		83,800	47,000	10,200
	5	72,300	39,333	6,367
	10	60,800	31,667	2,533
	15	49,300	24,000	(1,311)

TABLE IV
Estimated Annual Balance Sheet
for
50 Week, 5 Days per Week Operation

	Shift Hours	3 24	2 16	1 8
1. Gross Revenue @ 5¢/kwh		48,000	32,000	16,000
10¢/kwh		96,000	64,000	32,000
2. Cost				
Depreciation, 10 yrs (100,000)		\$ 10,000	\$10,000	\$10,000
Interest, 10%		10,000	10,000	10,000
Insurance, Taxes, Msc., 2%		2,000	2,000	2,000
Front Loader Tractor, \$10/Day		3,600	3,600	3,600
Overhaul and Maintenance		4,000	3,000	2,000
Operator Wages, \$20/hour		15,000	10,000	5,000
Subtotal		\$ 44,600	\$38,600	\$32,600
Fuel @ 0 \$/ton		0	0	0
5 \$/ton		8,250	5,500	2,750
10 \$/ton		16,500	11,000	5,500
15 \$/ton		24,750	16,500	8,250
Total W/Fuel @ 0 \$/ton		44,600	38,600	32,600
5 \$/ton		52,850	44,100	35,350
10 \$/ton		61,100	49,600	38,100
15 \$/ton		69,350	55,100	40,850
3. Profit and Loss				
	Fuel			
Revenue @ 5¢/kwh	0 \$/ton	3,400	(6,600)	(16,600)
	5 \$/ton	(4,850)		
	10 \$/ton			
	15 \$/ton			
Revenue @ 10¢/kwh	0 \$/ton	51,400	25,400	(600)
	5 \$/ton	43,150	19,900	
	10 \$/ton	34,900	14,400	
	15 \$/ton	26,650	8,900

Figure III : Net Annual Profit vs Electricity Cost
200 KWe Gasifier Engine Generator Unit 5 day
week, 24 hours/day 50 weeks/year

Figure IV : Net Profit vs Electricity Cost 200 KWe
Gasifier Engine Generator Unit 7 day week, 24 hours/
day 50 weeks/year

TABLE V

Average Price of 100 Therms of Residential Heating Gas and 100 Gallons
of No. 2 Fuel Oil by Area

June 1978

Standard Metropolitan Statistical Areas	Residential heating rates average price per 100 therms.		Fuel Oil No. 2 average price per 100 gallons	
	May 1978	June 1978	May 1978	June 1978
Atlanta	21.67	21.65	----	----
Baltimore	37.28	37.58	50.46	50.46
Boston	28.29	25.16	50.44	50.44
Buffalo	27.87	27.64	52.99	52.99
Chicago-N.W. Indiana	25.36	25.15	48.59	48.58
Cincinnati	25.82	26.87	----	----
Cleveland	19.97	20.14	----	----
Dallas	25.36	26.69	----	----
Detroit	25.34	25.50	48.90	48.90
Houston	32.36	32.39	----	----
Kansas City	16.79	16.82	----	----
Milwaukee	28.95	28.95	48.17	48.17
Minneapolis-St. Paul	25.82	25.76	¹ 48.42	48.27
New York-N.E. New Jersey	40.23	40.31	51.48	51.48
Philadelphia	30.56	30.55	49.78	49.65
Pittsburgh	24.22	23.98	----	----
St. Louis	24.99	24.97	48.44	48.44
San Francisco-Oakland	20.99	20.99	----	----
Seattle	31.96	31.96	51.26	51.26
Washington, D.C.	39.96	33.40	51.82	51.82

¹

Revised

 $\bar{x} = 50.04$ $s = 1.61$

TABLE VI

Net Monthly Bills to Residential Customers for Specified Amounts of Gas
by Area

June 1978

Standard Metropolitan Statistical Areas	Monthly bills for use other than heating						
	10 therms		25 therms		40 therms		June 1978
	May 1978	June 1978	May 1978	June 1978	May 1978	\$/10 ⁶ BTU	
Atlanta	4.39	4.39	7.88	7.87	11.13	2.78	11.13
Baltimore	6.94	6.98	12.00	12.08	17.05	4.29	17.17
Boston	7.02	6.73	12.37	11.65	17.01	3.45	15.87
Buffalo	5.69	5.66	10.12	10.06	14.73	3.66	14.64
Chicago-NW Indiana	3.99	3.97	8.31	8.25	12.55	3.12	12.47
Cincinnati	4.21	4.32	8.48	8.74	12.46	3.22	12.87
Cleveland	4.18	4.20	7.34	7.39	10.51	2.65	10.59
Dallas	3.15	3.27	6.91	7.22	10.72	2.80	11.21
Detroit	5.47	5.48	8.77	8.81	12.08	3.04	12.15
Honolulu	10.82	11.44	21.77	23.14	32.84	8.77	35.09
Houston	5.43	5.43	11.20	11.20	16.85	4.22	16.86
Kansas City	3.44	3.44	6.23	6.23	8.81	2.21	8.82
Los Angeles-Long Beach	4.60	4.60	6.66	6.66	8.73	2.18	8.73
Milwaukee	5.15	5.15	9.36	9.36	13.57	3.39	13.57
Minneapolis-St. Paul	5.30	5.29	8.91	8.89	12.53	3.13	12.50
New York-N.E. New Jersey	8.56	8.61	16.17	16.20	22.95	5.9	23.58
Philadelphia	5.03	5.04	10.69	10.69	15.51	3.88	15.50
Pittsburgh	4.67	4.64	8.21	8.14	11.68	2.90	11.58
St. Louis	4.00	4.00	8.93	8.93	13.46	3.36	13.45
San Diego	3.28	3.28	6.07	6.07	9.28	2.32	9.28
San Francisco-Oakland	2.68	2.68	4.86	4.86	7.59	1.9	7.59
Seattle	5.11	5.11	10.48	10.48	15.75	3.94	15.75
Washington, D.C.	17.42	7.35	12.07	11.90	16.70	4.11	16.43

¹Revised - See Table 6A $\bar{x} = 5.26$ $s = 1.95$ $\bar{x} = 3.53$ $s = 1.46$

X. WASTE HEAT UTILIZATION

The heat rejected to the atmosphere from the engine cooling water, engine exhaust, and off-gas condensor are estimates to be as follows:

Cooling Water	770×10^3 BTU/hr @ 200 °F Initial Temp.
Exhaust	623×10^3 BTU/hr Cooled From 900 °F - 300 °F
Off-Gas	332×10^3 BTU/hr Cooled From 1000°F - 200 °F

The heat required to dry the wet fuel from 13.2 wet tons per day to 6.6 dry tons per day is estimated to be 633×10^3 BTU/hr. A rotary drum dryer to remove the water from the fuel before entering the gasifier, using the engine exhaust and off-gas condensor cooling air as energy sources, would improve the gasifier conversion efficiency and reduce the off-gas condensor load. Such a rotary dryer system might cost \$25,000.

The heat energy for drying the wet fuel could be obtained by using a portion of the off-gas in a low BTU burner. It is estimated that it would require 68 CFM of 155 BTU/SDCF gas to feed the burner. This represents about 23% of the 200 KWe gasifier capacity.

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