



Research and Development

EVALUATION OF A PROCESS
TO CONVERT BIOMASS
TO METHANOL FUEL

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Evaluation of a Process to Convert Biomass to Methanol Fuel

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FOREWORD

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Glossary

| | |
|------|--|
| ASME | American Society of Mechanical Engineers |
| atm | atmospheres |
| BMS | burner management system |
| FV | Solenoid flow valve |
| HPR | hydropyrolyzer |
| HX | Heat exchanger |
| MSR | methanol synthesis reactor |
| P&ID | process and instrumentation diagram |
| PID | proportional, integral and derivative |
| psia | pounds per square inch, absolute |
| psig | pounds per square inch, gauge |
| scf | standard cubic feet |
| scfm | standard cubic feet per minute |
| SPR | steam pyrolysis reactor |

Metric Conversions

| <u>Metric unit</u> | <u>English equivalent</u> |
|--|--------------------------------------|
| degrees C | $(\text{degrees F} \times 9/5) - 32$ |
| kilogram (kg) | pound $\times 2.2$ |
| kilopascal (kPa) | psi $\times 20.88$ |
| liters per minute (L/min) | cubic feet per minute $\times 0.035$ |
| meter (m) | foot $\times 3.28$ |
| millimeter (mm) | inch $\times 0.039$ |
| megapascal (MPa) | psi $\times 20885$ |
| Normal cubic meters per hour (Nm ³ /hr) | scfm $\times 0.0283 \times 60$ |

Abstract

The U.S. Environmental Protection Agency and the University of California entered into Cooperative Agreement 824308-010 to develop and demonstrate the Hynol Process, a high-temperature, high-pressure method for converting biomass to methanol fuel. The period of performance was June 1995 to June 2000. At the bench scale, the Hynol Process has demonstrated about 75% carbon conversion efficiency with indications of low tar formation. A model developed during the bench scale testing predicts an increased carbon conversion efficiency from 75% to 88% for an increase in residence time from 1 to 7 hours. The Hynol reactor was designed to have a 7-hour residence time. The high efficiency and the potential for low tar formation hold promise for a cost effective technique for renewable fuel production.

The specific requirements of the Cooperative Agreement were for the UC Riverside College of Engineering-Center for Environmental Research and Technology (CE-CERT) to develop a pilot-scale (23 kg of feedstock/hr) Hynol facility and to operate it using woody biomass and natural gas as cofeedstocks. Cofunding was provided by the California Energy Commission, and the Riverside County Waste Resources Management District. CE-CERT contributed substantial additional funding.

The research focuses on producing methanol for use in a vehicle; however, the process can be modified to yield hydrogen, methane, or other fuels suitable for use in electricity generation. It also will contribute to environmental goals by reducing emissions of greenhouse gases, by providing a clean fuel, and by mitigating problems associated with disposal of carbonaceous waste. The key objective was to demonstrate the biomass gasification step of the Hynol Process and its reactions to produce a synthesis gas. The processes involved in converting this gas to fuel are demonstrated commercial technology, and those systems can be added later.

Design and construction, based on equipment specifications developed by Acurex (EPA Report No. 600/R-96-006, Hynol Process Engineering: Process Configuration, Site Plan, and Equipment Design, February 1996), were originally expected to be completed by June 1998. Because of errors in the report and problems with the facility, the actual completion date has been pushed back. This report describes numerous design considerations that were reviewed; design modifications made; and preliminary results from operating the facility.

1. Introduction

1.1 Background and Theoretical Approach

Producing methanol from biomass offers significant environmental, energy, and economic advantages over other liquid fuel resources. Methanol is cleaner-burning than gasoline, so its widespread use can contribute to air quality improvements in urban areas. The fuel also can be produced from domestic, renewable resources, which brings advantages in emissions of greenhouse gases, energy security, and local jobs.

Process simulation studies indicate that the Hynol process should result in improved efficiencies in methanol production through increased yields over conventional processes. The advantages of the Hynol Process to the EPA are its potential to (1) produce liquid

transportation fuel at a cost competitive with conventional fuels when used in fuel cell vehicles; (2) increase the quantity of biomass that could be produced as energy crops at a price acceptable for conversion to transportation fuel, thus increasing farm income; (3) displace more petroleum fuel than any other process based on biomass as a source of energy; and (4) achieve greater overall net reduction of greenhouse gas emissions from the U.S. vehicle fleet than any other biofuel option.

The Hynol Process originated at Brookhaven National Laboratory as a method for increasing the yield of fuel from conversion of biomass (Steinberg and Dong, 1994a). Originally conceived to operate with a coal feedstock, the process has been applied to co-processing biomass with fossil fuels, coal, oil, and gas at high temperature and high pressure. The process produces

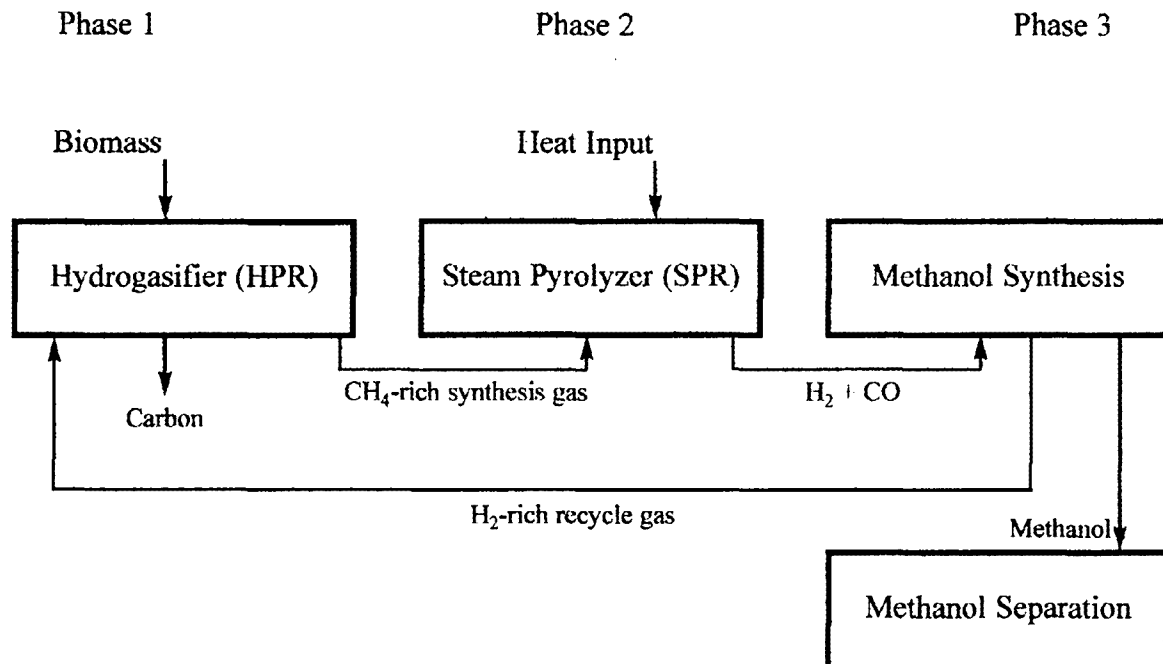


Figure 1-1. Hynol Process flows.

methanol, a liquid fuel that can be used for transportation, industrial processes, electrical power generation, and military needs. Alternatively, the process can be modified to produce hydrogen or other chemicals for industrial uses.

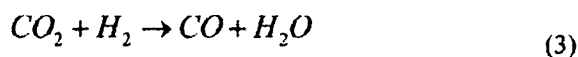
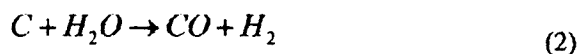
The process involves three phases (Figure 1-1).

1. Reaction of biomass in a hydrogasifier, also referred to as a hydrolyzer (HPR).
2. Steam pyrolysis of the resulting gas, which produces a synthesis gas.
3. Methanol synthesis, which leaves a recycle gas that can be returned to the HPR and waste heat that can be returned to the steam pyrolyzer (SPR).

The basic Hynol Process consists of two reactions:

1. Hydrogenation (or hydrolysis) of the carbonaceous feedstock to produce methane.
2. Endothermic reaction of methane with steam to produce hydrogen and carbon monoxide (steam pyrolysis).

For methanol production, the carbon monoxide formed in the steam pyrolysis step is catalytically combined with the hydrogen in a third phase to produce methanol. Excess hydrogen is recycled as a feed gas for hydrolysis. Biomass is fed into a fluidized-bed HPR and reacted with recycled H_2 -rich process gas at 30 atm pressure and 800 °C (Steinberg and Dong, 1994b). Steam at a rate of 0.2 kg per kg of biomass is simultaneously fed into the HPR. The independent reactions taking place in the HPR can be expressed as:



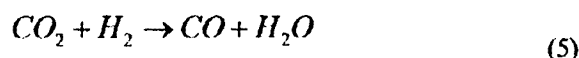
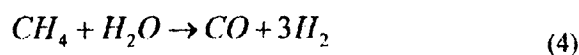
The process gas produced in the HPR contains 13 mole % CO , 38 mole % H_2 , and 20 mole % CH_4 . Nitrogen that comes from the feedstock forms inert N_2 in the process gas and is taken into account in the calculation of equilibrium gas composition. The objective is to demonstrate conversion of the carbon in biomass feedstock in the HPR to be over 87%. The unconverted carbon is withdrawn from the reactor with ash in the form

of char. The char either can be used as fuel for the SPR (if separated from the sand, limestone, and/or kaolinite) or sequestered.

Reactions (2) and (3) are endothermic and require additional energy input to the gasifier. This is why conventional gasification processes need oxygen or air to supply combustion heat by burning some carbon in the feedstock within the gasifier. In the Hynol Process, however, thermal energy from recycled gas combined with reactions in the HPR allows for an energy-neutral gasifier without the need for an internal or external heat supply. The hydrogasification reaction (1) between the carbon in feedstocks and the hydrogen in the recycled process gas is exothermic and in theory provides sufficient heat for reactions (2) and (3) when preheated by heat exchange with the SPR effluent stream.

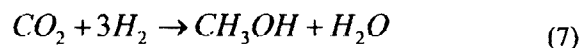
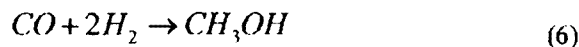
Before entering the SPR, process gas from the HPR of the Hynol Process usually needs to be cleaned up to remove particulate matter and impurities that may contaminate catalysts in the subsequent reaction steps. Conventional hot gas cleanup methods can be used for this purpose. Natural gas feed can be added prior to the HPR filter to cool the gas stream and maintain a more filter-friendly operating environment.

The process gas is then introduced to the steam reformer (alternatively called the SPR) where HPR outlet gas and natural gas co-feedstock react with steam to form CO and H_2 . The steam reforming can be described by two independent reactions:



The SPR is a steam reformer using a conventional nickel catalyst but operating at higher temperature (900-950 °C and higher pressure (30 atm). The mol ratio of steam to carbon entering the SPR is 2.5. A catalyst-packed tubular externally-fired furnace reactor similar to a conventional natural gas reformer furnace reactor is used for the SPR. Steam feed ratio is 1.2 kg per kg of biomass. Methane feed into the SPR is at a rate of 0.5 kg per kg of biomass. The H_2 and CO concentrations in the exit gas of the SPR are increased to 60% and 21%, respectively. The process gas is then passed through a gas heat exchanger, where it is cooled. The recovered heat is used to heat the recycled gas. The process gas is cooled for the methanol synthesis reactor (MSR) feed. The steam produced in this way is about 1.52 times biomass feed rate in weight, which makes steam self-sufficient within the system.

The cooled process gas then enters the MSR to produce methanol. The reactions taking place in the MSR are:



The methanol synthesis is performed at 30 atm and 260 °C. The MSR reactions are highly exothermic, so the released process heat can be extracted from the MSR and used to dry the biomass feedstock. Methanol and water are separated from the MSR effluent gases by a condenser and fractionated by distillation to obtain a pure methanol product. To increase the conversion of CO in the MSR, the uncondensed gas from the condenser is partially returned to the MSR. Using this approach, the recycle ratio of the internal loop is 4 moles per 1 mole of input process gas from the SPR. The net result is a 90% conversion of CO to methanol in the MSR. Unlike conventional processes where CO conversion in the MSR is a most critical parameter affecting the efficiency losses of the process, the Hynol Process reprocesses the unconverted material by recycling the gas to the HPR and thus prevents losses of process gas constituents. For this reason, the Hynol Process obtains a high thermal efficiency, even though the CO conversion through the MSR may be lower than that of conventional processes.

The condenser operates at 50 °C. The gas exiting the MSR system is introduced to the gas heat exchanger, after a small amount of gas (3.7% of the recycled gas) is purged, eliminating the accumulation of inert nitrogen in the system and keeping the nitrogen concentration in the system below 2.5 mole %. We are designing the system to accommodate a range of steam and natural gas feeds. The entry points of the steam and natural gas prior to the HPR or SPR can also be adjusted as indicated by revised process modeling assessments.

1.2 Design and Performance Issues

The technical challenges of the Hynol gasifier are to optimize carbon conversion, minimize tar formation, control alkali agglomeration, maintain gasification bed temperatures, achieve steady-state operation, and demonstrate particulate control. In addition, reliable operation of the bed height estimation, biomass feed system, ash removal process, cyclone efficiency, alkali sampling system, and tar sampling system must be demonstrated.

The Hynol facility at Riverside was designed around optimizing carbon conversion of biomass in the gasifier. Carbon conversion is strongly dependent on the residence time inside the reactor (Dong and Cole, 1996; Dong, 1998). There is a tradeoff with too long a residence time because higher residence times reduce biomass throughput. A three-parameter kinetic model was developed and used for quantitatively investigating biomass conversion and reaction rate phenomena (Dong et al., 1996, 1998) as part of a project sponsored by the EPA. The effects of particle size, gas velocity, system pressure, reaction temperature, and gas composition on biomass hydrogasification behavior were investigated. The conclusions from this study were the basis for the operation of the Hynol reactor located at UC Riverside. Below, the conclusions are summarized, and their significance in the design of the reactor is discussed.

1. The carbon conversion takes place in two stages. There is first a period of rapid reaction of biomass thermal decomposition (seconds), followed by a slow reaction of the residual char (hours). The twofold residence time was used to design the reactor bed height, the expanded zone, the cyclone, the fluidization velocity, and the bed media particle size. The bulk of the biomass is converted in first few seconds while the residual char is left in the fluidized bed until the particle size is small enough to pass through the cyclone. The cyclone was designed to return 95% of the particle fines to the reactor. The reactor zone (3 m height, 150 mm diam) was designed for the rapid reaction of biomass. The expanded zone (1.5 m height, 300 mm diam) was designed for the slow residual char conversion. The expected velocities in both sections are 0.3 m/s and 0.08 m/s, respectively.
2. The developed model can be used to predict biomass conversion as a function of reaction time assuming similar conditions for the tests. The model is used to estimate expected carbon conversion efficiencies for each test based on expected residence time from the operating conditions.
3. The gas film mass transfer is negligible at gas flow rates greater than 0.1 m/s. This information supports the decision to operate the fluidized bed at a velocity of 0.3 m/s.
4. Biomass particle sizes less than 3.2 mm do not have a strong impact on the rapid reaction rate. Although particle sizes below 3.2 mm are recommended, CE-CERT is using white oak from the waste stream of a hardwood door manufacturer. The particle size is

- distributed with particles ranging from 6.4 mm to less than 3.2 mm. The larger 6.4 mm particles are expected to have a small effect on conversion efficiency because the designed residence time is greater for the pilot scale tests than the bench scale tests.
5. Nearly all the hydrogen and oxygen can be converted into gas products in 20 minutes using 3.2 mm wood particles. The Hynol reactor was designed to have a residence time of approximately 7 hours assuming the internal cyclone is 95% efficient.
 6. At 30 atm and 800 °C, about 87% of poplar wood (which was used in earlier bench-scale research) or 75% of its carbon content can be converted in 60 minutes. Extending the reaction time and increasing particle attrition in the reaction zone can achieve higher conversions. The model predicts that an increase in carbon conversion efficiency from 75% to 88% can be achieved with a residence time of approximately 7 hours. CF-CERT expects an 85% carbon conversion efficiency for the tests performed under this testing program.
 7. Increases in reactor pressure from 10 atm to 60 atm only slightly increase biomass conversion. The reactor was designed for operation at 30 atm to reduce capital costs. Future designs should be based on desired throughput and reactor cost for optimized pressure rating. The 30 atm design base is a good starting point for evaluating the process. Once the process is confirmed, economics can be investigated.
 8. Biomass conversion is greatly increased when reaction temperatures are raised from 800 °C to 950 °C. Although higher temperatures are desirable, alkali formation also increases with higher temperature. Therefore, it is desirable to operate at 800 °C + 50 °C. Alkali formation was not investigated in the reaction rate experiments by Dong and Cole (1996).
 9. The biomass conversion is proportional to the hydrogen partial pressure in the recycle feed gas. During operation one way to improve biomass conversion is to increase the hydrogen partial pressure. This will be useful when integrating phases 2 and 3.
 10. The biomass conversion is proportional to steam partial pressure in the recycle feed gas. Increasing the steam partial pressure may increase the biomass conversion, but it reduces reactor temperatures. Again, this is a tradeoff between high conversion and maintaining bed temperatures.
 11. When the methane co-feeding in the recycle is less than 15%, its effects are negligible to the biomass conversion. No methane co-feeding will be performed during phase 1 of the Hynol project, but it will be investigated for phases 2 and 3.
 12. Carbon monoxide and carbon dioxide concentrations have no significant effect on the gasification behavior. This information was used to eliminate those variables that could affect the conversion efficiencies during operation.
 13. The bench scale hydrogasification experiments with poplar have shown the potential for low tar formation. The Hynol reactor sample system was designed to evaluate tar formation during gasification tests.
- Optimum gasification may not be ideal for steady-state operation. Alkali formation was not studied in the thermo balance reactor, and alkali agglomeration is very common in coal and biomass gasifiers (Miles et al., 1998; Unnasch, 1996). One solution to the problem of alkali formation is to use an adsorbent or chemical alkali getter. Kaolinite was found to be the most efficient in alkali control, but this is based on equilibrium models and has not been tested in gasification (Unnasch, 1996). Once steady-state hydrogasification is achieved, the alkali problem will be investigated.
- Another problem with optimum carbon conversion is that the high bed temperatures increase the alkali formation concentration, and thus require the use of more alkali getter. Unnasch (1996) found that alkali formation starts at temperatures greater than 750 °C and peaks at 850 to 900 °C. Therefore, gasification temperatures need to be optimized for carbon conversion, but not at a high cost to alkali formation. There is a balance where too much getter is needed to offset the gains in carbon conversion. This operating point will be a function of the biomass and alkali getter used.
- The design of the internal cyclone needs to be evaluated for its effectiveness and performance. This can be accomplished by operating at steady state and sampling the ash removed at the bottom of the filter compared

with the ash removed from the bottom of the gasifier. The cyclone was designed to remove 90-95% of the large particles and the filter is designed to remove 99.99% of the fines including particles as small as 0.5 μm . CE-CERT has installed a high-pressure sample sys-

tem to evaluate the filter and cyclone performance. The sampling system also was designed to sample for tars and alkalis. However, due to design limitations, the sampling of tars and alkalis needs improvement to accurately follow ASTM standards.

2. Methodology

The basis for the approach to this project was provided by Unnasch (1996). The HPR system will initially be operated independently, decoupled from the SPR and MSR. For this reason, two elements of the Hynol system will not be available for decoupled HPR operation and will need to be simulated (i.e., recycle gas from the MSR and its heat source, the exit gas from the SPR). The recycle gas will be simulated by mixing gases from tube trailers with natural gas, steam, and vaporized liquid CO₂. Since the SPR will not be operating, the inter-reactor heat exchanger (preheating the recycle stream) will not operate at a high enough temperature, and approach temperatures will be too low to provide for the required HPR inlet temperature. An electric heater will provide the additional heat energy to the recycle gas that normally would be recovered from the SPR effluent stream. A flowsheet for the decoupled HPR system needs to consider the source and temperature of the simulated recycle gas since these gases will not be produced from system recycle but rather from bottled gases.

The hydrogen, carbon monoxide, and nitrogen are fed from truck tube trailers and mixed to simulate the recycle gas in the fully integrated system. The inlet gases at ambient temperature are heated in the heat exchanger by the HPR outlet gas. An exhaust gas heat exchanger converts water to steam, which is injected after the heat exchanger. The mixture passes through an electrical heater before entering the burner where methane is injected.

The hydrogasifier is fed with a mixture of solids, primarily chipped wood (white oak, ~6.4 mm chips) and an alkali absorbing (gettering) agent. The green waste and getter are mixed together and fed into a day bin and lockhopper; the sand and getter can be fed separately directly into the lockhopper or mixed with the biomass feed. A screw-feeder meters the solids into the reactor vessel where they are fluidized.

Unreacted solids and ash are removed from the reactor in two ways. The solids are removed directly from the bottom of the reactor using a lockhopper system. Lighter ash is removed from the top of the bed from an overflow passage, on the side of the vessel, which empties into a lockhopper system.

An internally mounted cyclone separates the majority of particles from the exiting gas. The outlet gas passes through a filter which is pulse-cleaned with nitrogen. The hot outlet gas is heat-exchanged with the cold inlet gas.

Some elements of the integrated Hynol system were incorporated into the design of the HPR system. The SPR uses an air compressor and natural gas compressor, and it should use a steam jacket. All of these systems are common with the HPR system and were incorporated into the HPR system design. The demand for methane and air vary with the different Hynol cases, so the feed requirements were incorporated into the HPR system.

The HPR system process flow diagram includes the following features that are of interest or differ between the theoretical integrated system and the actual decoupled system:

1. H₂, CO, CO₂, and N₂ are added from bottled gases, heated with a heat exchanger, and then heated further with an electric heater. These gases simulate some of the recycled HPR feed.
2. Steam from a heat exchanger is added upstream of the electric heater. This flow simulates both water vapor that is in the recycle stream and steam that is added to the HPR system. The electric heater raises the temperature to 1000 °C. Higher temperatures are difficult to achieve with an electric heater.
3. Provisions are also made to add natural gas downstream of the HPR. This stream represents the

methane feed to the SPR in the full (complete) system. About 10 percent of this stream is split off and used to purge the cyclone in the HPR. The balance of the natural gas is added after the HPR. For decoupled HPR operation, most of the methane need not be added to the system.

4. Methanol is present in small percentages in the recycle gas. However, the methanol would dissociate in a heat exchanger with an 888 °C outlet temperature. Therefore, for the decoupled HPR system, methanol should be added in the form of its constituent CO and H₂. The mass-flow (associated with methanol vapor) entering the HPR is held constant between the decoupled and integrated systems.

5. Some lockhopper pressurization gas carries over into the HPR, since the biomass voidage volume in the

lockhopper is pressurized with nitrogen. Consequently, nitrogen gas enters the HPR. The mass and enthalpy of the nitrogen should be considered in the energy balance for the process. They are included on the flow sheet for the decoupled HPR.

6. Air and natural gas are combusted to warm up the HPR before startup. The corresponding flow rates are shown in the process flow diagram. Nitrogen that is heated with the electric heater will also be used during start-up operations. Nitrogen can flow through the electric heater, which will prevent the heater wires from overheating before simulated recycle gas is added to the system. Air may also need to be added upstream of the electric heater to allow for periodic oxidation of the heater wires.

3. Facility Construction

Construction began in February 1996 and was completed by March 1998. Modifications were made from June 1997 through December 1998. The first gasification test was completed in December 1998. Since December 1998, CE-CERT has completed three more gasification tests. Each test has shown some successes but revealed other design/operation problems. CE-CERT continues to perform gasification tests and process design shake-down evaluation.

There were a variety of delays with the construction, installation, and process evaluation that resulted in the schedule shown in Figure 3-1. The *delivery delays* were due to construction of a forged burner tee, repair to the refractory, and fabrication of a high-temperature inconel distributor and cyclone. The *design modification delays* were due to curing the refractory on site, repairing a large crack on the main burner spool piece, and installing the high-pressure feed system. The *final process delays* were due to process modifications that included repairing the feed system valves, biomass bridging, heater elements, ash removal valves, process controls, flow meter calibrations, and the burner management system.

CE-CERT has successfully demonstrated the automated high-pressure biomass feed system, maintained bed

temperatures, achieved reliable burner operation, achieved reliable electric heater operation, and performed consistent ash removal. The main design challenges remaining are to overcome an agglomerating problem in the Hynol reactor and to perform steady state gasification.

Arcadis designed the vessels, refractory, and process flow, and CE-CERT designed the layout of the Hynol gasification test facility. CE-CERT also is responsible for operating and evaluating the Hynol process. The Arcadis design details can be found in *Hynol Process Engineering: Process Configuration, Site Plan, and Equipment Design* (EPA-600/R-96-006, Office of Research and Development, Washington, DC) (Unnasch, 1996). The facility layout houses a 59.4 Nm³/hr air compressor, a 24.8 MPa, 6.8 Nm³/hr natural gas compressor with 84,950 liter storage, a 1.7 Nm³/hr CO₂ booster pump, a 300kVA electrical distribution panel, a biomass bulk storage area, a tube trailer bulk storage area, and a control room (Figure 3-2). As part of the project, the facility layout was designed to accommodate future phases 2 and 3 of the Hynol Process development.

The site development started in February 1996 and was finished by May 1996. Part of the site development was

| Description | 1996 | | | | 1997 | | | | 1998 | | | | 1999 | | | |
|----------------------------------|------|---|---|---|------|---|---|---|------|---|---|---|------|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Site Development | ■ | ■ | ■ | ■ | | | | | | | | | | | | |
| Vessel Design/Construction | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Structure/Vessel Installation | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Inconel Distributor and Cyclone | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Design Modifications | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Electrical/Controls/Acquisition | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Process Modifications | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Gasification Testing | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Operational Design Modifications | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |

Figure 3-1. Hynol facility schedule.

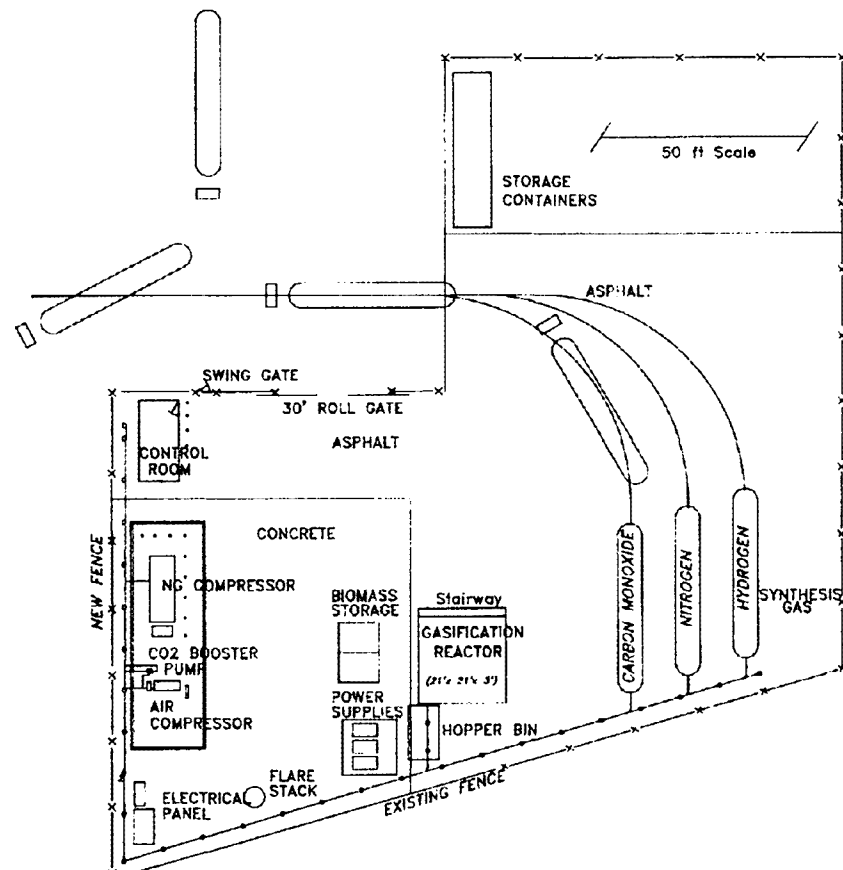


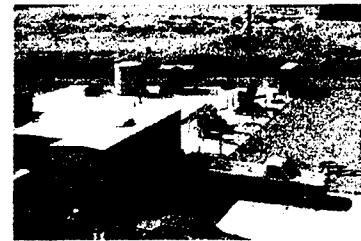
Figure 3-2. Hynol facility layout at CE-CERT, 1200 Columbia Avenue, Riverside, CA.



a



b



c

Figure 3-3. Hynol site development work (a,b) ground preparation (c), asphalt and concrete completion.

a geological study and an environmental impact report; see Appendices I and II for copies of these studies. Figure 3-3a,b,c show the progress of work from earth moving to the completed foundation.

The vessel construction was contracted through Bay City Boilers, and the refractory was contracted through Dee Engineering. The vessels were constructed out of schedule 80 pipe except for the large burner spool pieces. ASME codes required the tee section to be

forged. The forging delayed the delivery date and increased the vessel cost. The vessels were finished and delivered by March 1997 (Figure 3-4).

The steel structure, foundation and lighting were contracted through Martec International. Figure 3-5 shows a model layout of the structure and vessels. Once the vessels arrived at CE-CERT, the structure was erected in about two weeks (Figure 3-6). CE-CERT found a structure problem that could have been serious if it had gone



a



b

Figure 3-4. Vessel fabrication at Bay City Boilers. Main reactor piece 24 inch schedule 80 pipe with class 181.4 kg flanges (a); forged burner tee (b).

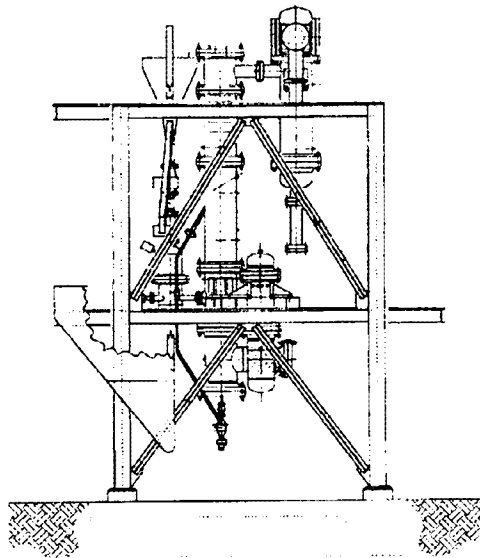
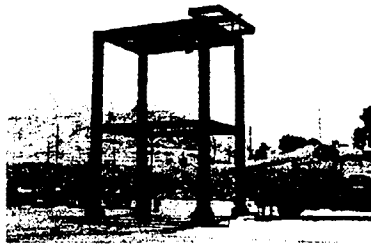


Figure 3-5. Structure design concept drawing with all the vessels.



a



b

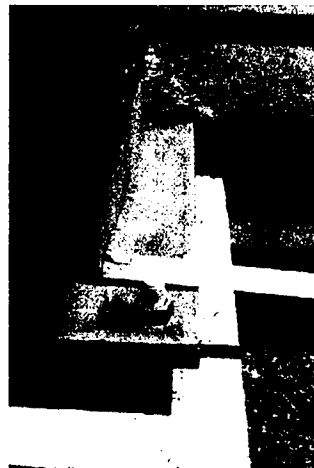


c

Figure 3-6. Structure erection: (a) vertical uprights with cross member, (b) floor support, and (c) grating.



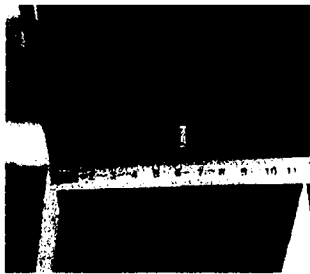
a



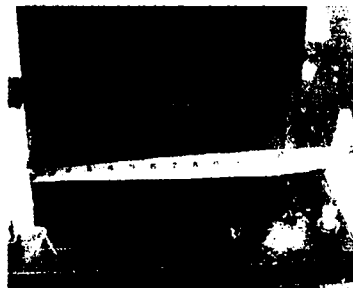
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c



d



e

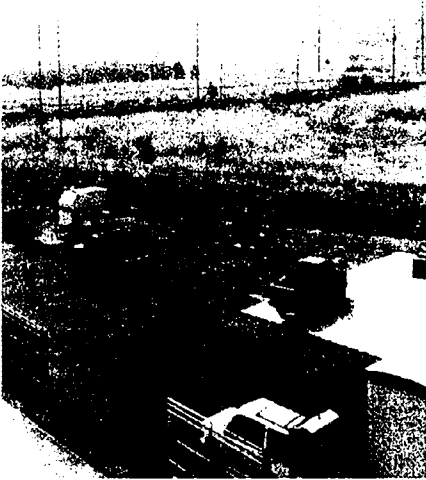
Figure 3-7. Twisting problem with one of the main I beam supports: (a) safety officer pointing at a twisting main support I beam, (b) side view front, (c) side view back measure, (d) front view measure, and (e) back view measure.

unnoticed: One of the main four I-beam supports was twisted due to eccentric loading legs (Figure 3-7). The problem was repaired during vessel installation.

HP Construction was responsible for installing the vessels and completing the pressure leak test (Figure 3-8). The vessel installation was delayed due to problems with the inconel pieces, refractory curing, installing heat exchanger insulation, and repairing the burner refractory. The vessel installation was completed March

1998 by successfully maintaining 5.2 MPa for 24 hours with a loss of no more than 10%.

Before the reactor could be operated, the control, instrumentation, and process equipment had to be installed. The extension of the schedule from June 1998 to December 1998 accounts for the time necessary to modify the process before operation of the facility could begin.



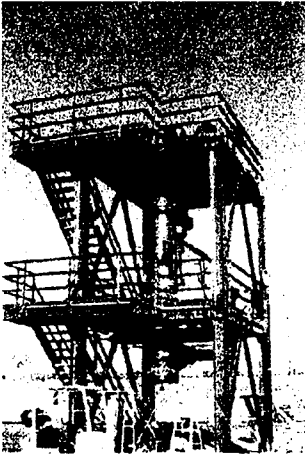
a



b



c



d



e

Figure 3-8. Vessel installation at CE-CERT's Hynol test facility.

4. Design Modifications

The vessels, refractory, process flow, and other mechanical systems were originally designed under a separate EPA project. The design details can be found in Unnasch (1996). This section describes the modifications to the original design. There were no as-built drawings provided by Arcadis or CE-CERT; the following subsections describe the as-built system. The design modifications are in chronological order.

4.1 HPR Reactor

Refractory

The refractory arrived damaged and brittle. In some sections the refractory would flake off when touched. CE-CERT hired a local refractory installer to repair the damaged areas using VSL 50 to provide a 51mm-thick hot face to the lightweight GreenCast 19L. The VSL 50 has a maximum temperature rating of 1371 °C, while GreenCast 19L has a maximum temperature rating of 1038 °C. The new material serves two purposes. First, it allows the hard surface for the high gas flows and ash to pass without damage to the refractory surface. Second, it protects the under layer refractory from overheating. Figure 4-1 shows some of the damage to the refractory and its repair.

Curing Process

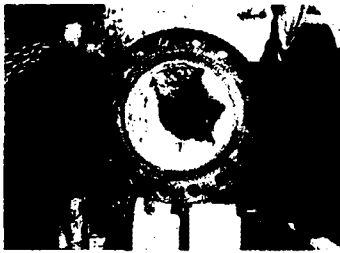
There were two options for curing the refractory: One was to have it done at Dee Engineering when the refractory was poured, and the other was to have the refractory cured at CE-CERT using the natural gas burner. When the vessels arrived at CE-CERT they were not cured, thus CE-CERT was given the task to use the burner system to cure the refractory. There were many problems with trying to cure the refractory that delayed progress by three to four weeks. The burner was unreliable, and the heat rate was too quick in the burner section and slow at the far end near the filter. Wet refractory should be heated no faster than 10 °C/hr according to

the refractory manufacturer. Ideally, the process should have taken only four to five days, not three to four weeks. Also, the curing process was a 24-hour operation, thus making small problems larger due to time required to reheat cooled sections.

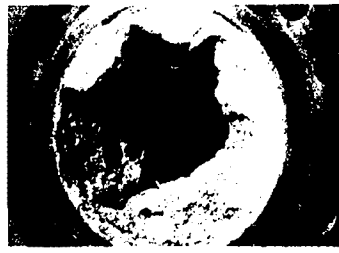
Burner Management System

While trying to cure the refractory, CE-CERT had to first modify the burner design to heat the vessels. The burner was designed to preheat the reactor, filter, and heat exchanger sections on start-up. The burner operation was controlled by a Honeywell Burner Management system (BMS). The purpose of the BMS was to control the flame based on a signal from a flame sensor. If the flame signal was below 1 volt, the gas valves were turned off. The BMS works as follows: The BMS starts the pilot and the igniter (similar to a spark plug on a vehicle). The BMS senses whether a flame is present by using a flame indicating rod. If no flame is sensed, the BMS turns off the pilot valves and stops the igniter after 30 seconds and waits to be restarted. If a flame signal is sensed, the BMS opens the main gas valves, closes the pilot valves and stops the igniter. The BMS continues to check the flame signal. If the signal gets weak (below 1 volt) the BMS turns off the main gas valves and waits to be restarted. The BMS function is common to a typical modern home furnace and gas laundry dryer; they operate as long as a good flame signal is present. The main difference was that our system operates in an enclosed environment at 689 kPa over ambient pressure. A high-pressure burner pilot/main system can be purchased, but they are typically custom-designed and expensive.

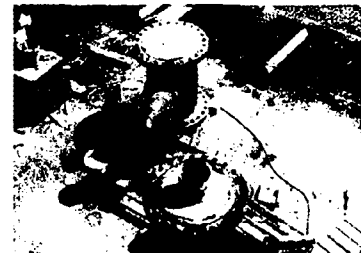
To start the burner, CE-CERT's responsibility was to set the pilot and main mixture valves for a lean burn. This was done using flow meters on the pilot and main gas valves. The air-to-fuel ratio was 9.5 to 1 (by volume), which was equivalent to a burner mixture of $\lambda = 1.1$ (lean of stoichiometric). Once the gases were set at a proper mixture, CE-CERT had to choose an appropri-



a



b



c



d



e



f

Figure 4-1. Refractory repair on the burner, reactor, and heater sections: Heater to burner section (a,b); repair to the burner tee and bottom R101 piece; loose refractory at the cyclone (d,e); and repair to the cyclone area (f).

ate flow velocity that would not blow out the flame. CE-CERT found it hard to prevent the pilot and main flames from self-extinguishing at the desired flow velocities. The high velocities were needed to preheat all the vessels. CE-CERT finally found a good pilot and main flow velocities that gave reliable flames. A good flame was confirmed using two thermocouples installed at the pilot and at the main flame areas.

Once a good pilot and main flame were achieved, the BMS was ready to be turned on. The BMS failed to work for two reasons:

1. The igniter was arcing on the flame rod, and the flame rod was not always in the flame. The high-voltage arcing between the flame rod and the igniter would send a high-voltage spike to the BMS, which would turn off the BMS instantly. To start the pilot, the BMS turns on the igniter and waits for the flame signal, but the igniter was arcing when the flame sensor sent an incorrect signal to the BMS. The flame rod could not be moved away from the igniter because it needed to be in the flame near the pilot and the pilot needed to be next to the igniter. CE-CERT then looked at home furnace pilot designs to understand the problem. Home furnace designs have a metal plate separating the igniter from the flame rod, while directing the flame to the flame rod.

2. The second problem was related to the function of the BMS when the main flame turns on. The problem is in the flame rod location. The sensing tip of the rod was in the pilot flame, not in the main flame. When the pilot flame is off, the flame rod needs to be in the main flame as well. The flame rod was too close to the base of the main flame, thus generating a low flame signal. This caused the BMS to turn off the main gas valves seconds after they are turned on. Moving the flame rod to a spot in the main flame would solve the problem when the main was on, but would not allow the pilot to sense a flame signal. CE-CERT chose to bypass the BMS system and to control the flame manually using flame temperature as the control signal.

Secondary Air

To reach the high volume (59.4 Nm³/hr air and 3.4 Nm³/hr natural gas) of heat needed to preheat all the vessels, the system had to be pressurized to 241 kPa, and secondary air was required to reduce flame temperatures and to move the heat throughout the vessels. The secondary air was designed to be at a 90-degree angle to the mid-point of the main flame. Secondary air at this location would carve a hole in the refractory wall, because the Green Cast 19L was too light to handle the high velocities. Replacement to the refractory in the burner section was not possible unless it was completely replaced. Instead, CE-CERT tried putting the secondary

air at the base of the flame, where the high-density refractory could handle the high velocities. At this location, the secondary air blew out the flame. The secondary air was then moved to the bottom of R101 (where the Mogas valves mount). This location delivered the heat to all the vessels as required. To keep the secondary air on the bottom of R101, CE-CERT will modify the start-up program to allow the Mogas valves to be open during the preheating process. Future designs should allow for secondary air to be added in the direction of the flame near the middle or end. A higher-density burner refractory is also recommended.

Low-Pressure Igniter

After operating the burner it was discovered that the flame and igniter rods were leaking at the electrical connections. CE-CERT found that the flame and igniter rods were low-pressure units and needed to be replaced with sealed high-pressure units. Because the BMS is not going to be used, CE-CERT has replaced the igniter unit with a high-pressure equivalent. Figure 4-2 is a photo of the old flame sparker and the new high-pressure unit fabricated by CE-CERT. During gasification test 1a, the modified spark system turned out to be unreliable, so a third design was necessary. This is described in Section 5 of this report.

Refractory Damage (#2)

Burner temperatures exceeded 1093 °C in order to heat up the entire reactor as necessary according to the cure SOP and to preheat the reactor for gasification tests. The refractory in the burner section was only rated for 1037

°C and failed during operation at temperatures above 1037 °C.

When the refractory was repaired the first time, a section in the burner was not repairable because of its location. Unfortunately, this section failed while the vessels were being cured. CE-CERT hired the same engineering firm that repaired the other refractory surfaces to repair the burner casting. The repair required removing the vessel from the structure, shipping it to B&B Engineering, and removing the old casting (Figure 4-3). The new refractory used GreenKleen 60 for the hot face and GreenCast 19L for the secondary lining. The hot face was 76 mm and the secondary lining was 89 mm. Before delivery to CE-CERT, the refractory was cured in an oven.

The new burner casting was rated to 1649 °C and has the rigidity of concrete. The burner skin temperature was expected to be no higher than 165 °C with a gas temperature of 1204 °C. The new casting should be able to withstand high gas velocities, which means the secondary air can be located back to the designed location near the burner flame. During gasification tests this refractory also failed during operation, as discussed in Section 5.

Burner Vessel Crack On Lower 18-inch Flange

CE-CERT found a surface crack on the lower 18-inch flange weld (Figure 4-4). Secondary inspection was required to determine the depth and details of the crack. Bay City Boilers hired an ultrasonic ASME inspector to X-ray the crack. The inspector found the crack penetrated a depth of 13 mm and almost 270 degrees around the flange. Because of the depth and length of the crack, the

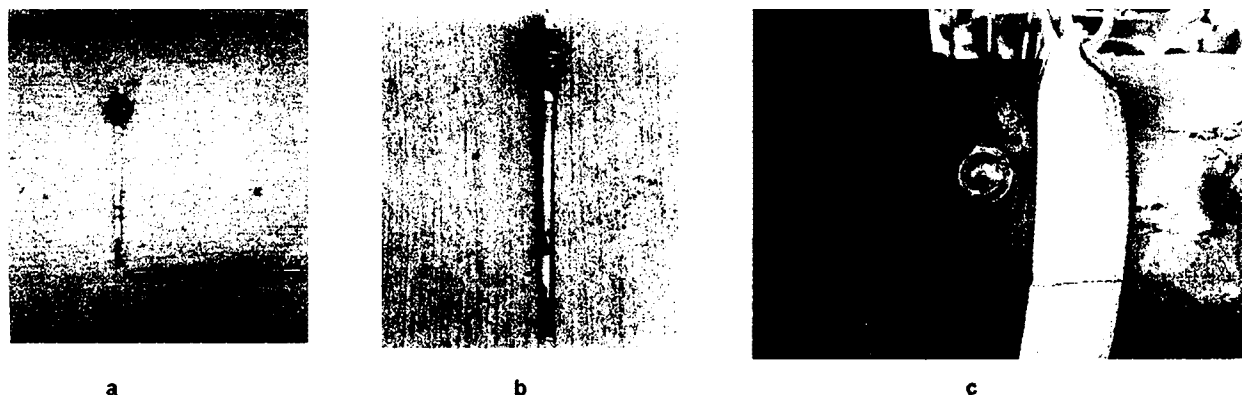
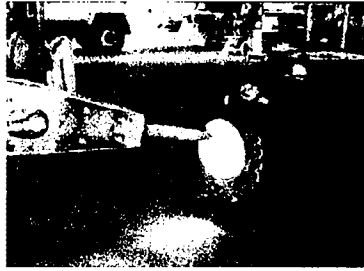


Figure 4-2. Igniter systems: (a) the old spark system; (b) modified spark system using a high-pressure electrical pass-through; and (c) pressure vessel for location of ground pilot system.



a



b

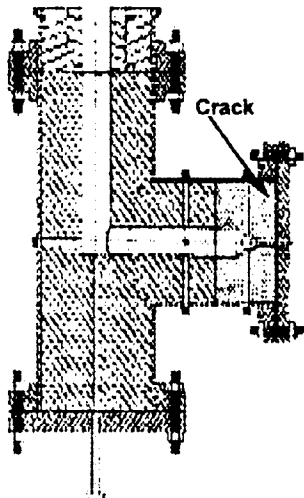


c

Figure 4-3. Removal of the burner spool piece refractory and internal refractory damage to the burner section.

flange was cut off and replaced. The vessel was removed and sent to Bay City Boilers (which warranted the repair for CE-CERT). After the crack was repaired and recertified, CE-CERT sent the vessel to a refractory shop to replace the refractory as mentioned earlier.

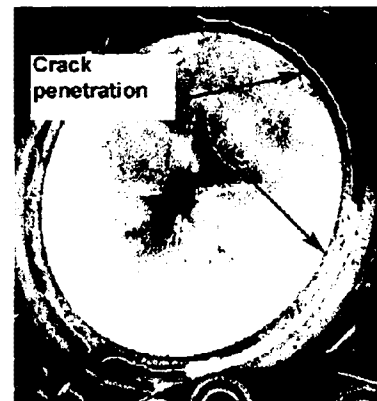
After finding one crack, CE-CERT hired an ASME inspector to test another 10% of the welds. If any serious cracks were found, CE-CERT would then test another 10% of the welds. No serious cracks were found, but two minor cracks on the heat exchanger vessel were identified (Figure 4-5). Both cracks were weld-



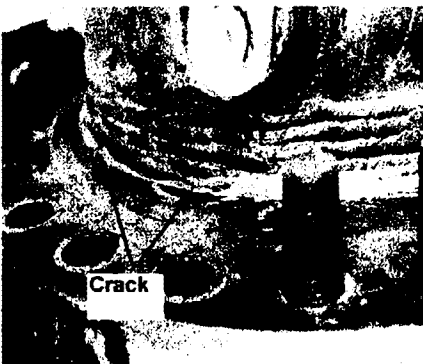
a



b



c



d



e



f

Figure 4-4. Crack investigation: (a) crack location CAD drawing; (b) crack inspection; (c) crack detail location and penetration; (d) crack close-up after grinding surface away; (e,f) burner piece removal.



Figure 4-5. Magnetic flux inspection on another 10% of the welds: (a) heat exchanger inspection; (b) process tubing connection showing crack and hole from poor penetration; (c, d) same process tubing repaired.

ed over using a certified welder, and the inspection grindings were brought up to full penetration. During the repair a pin hole in the connecting tubing was found and repaired.

4.2 Biomass Feed System

The feed system was designed to automatically feed biomass into the high-pressure reactor from a feed storage hopper. Interference problems and design operational problems had to be solved before the system was operational. In addition, the electrical work and control logic were not included with the design. CE-CERT took the responsibility to modify the mechanical interferences and to program and wire the system to the point of automation.

Feed System Overflow Chutes

The feed system overflow chute alignment was not designed properly and interfered with the feed valves and bucket elevator. The overflow chute was cut, rotated and re-welded to allow for proper feed system operation (Figure 4-6). The figures show the type of modifications and interferences that prevented the feed system from being installed. To make the feed overflow chute fit from the top of the valves to the storage bin, the angle needed to be decreased from 55° to 45°. The change in angle caused a bridging problem, which is discussed below.

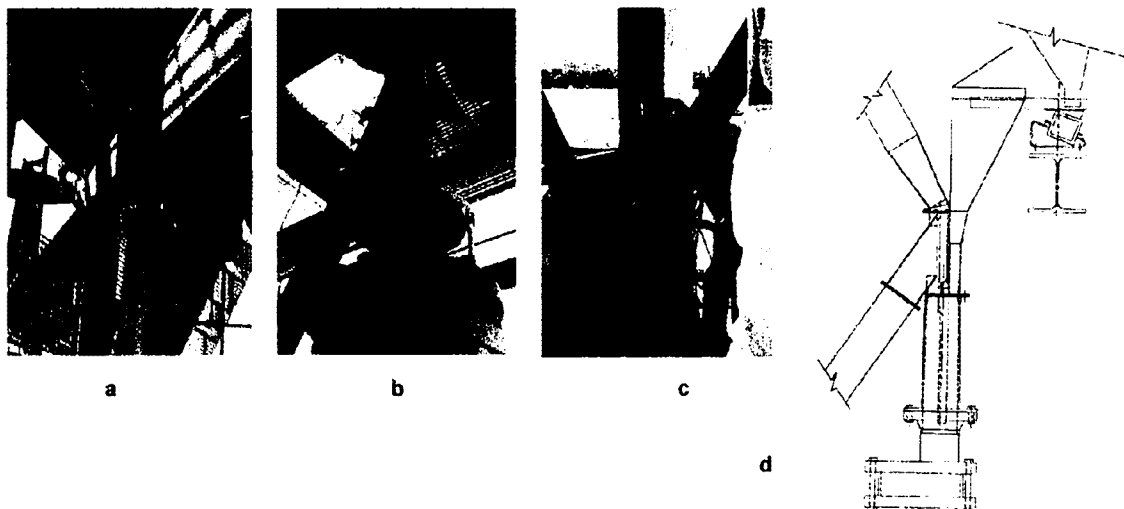


Figure 4-6. Modified overflow chutes for the biomass feed system: (a) interference with the feed valves; (b) modified angle to get overflow chute to mate with feed hopper; (c) connection to feed hopper; (d) orientation at the precharge hopper before entering the feed valves.

Feed System Storage

The biomass storage bin required extra mounts not covered in the preliminary site development. CE-CERT designed and installed new supports for the storage bin (Figure 4-7). A second problem was getting biomass into the storage bin. A truckload of white oak biomass was delivered to CE-CERT and conveyed into the storage bin using a rotary blower. It takes about one day to load enough biomass for a two-day gasification test. In the future, CE-CERT expects to rent a skip loader, which should do the same work in less than three hours.

The biomass is stored in the hopper and on the ground under nylon tarps. Moisture analyses were conducted throughout the year. The moisture content averages about 13% on the ground pile and 6% in the storage bin pile $\pm 2\%$. The average moisture value on the ground piles at a depth of 1.5 m was 6%, and there was no moisture difference for the piles in the storage bin.

Electrical Controls

The final assembly of the feed system required installing the vibrators, electrical controls, motor variable frequency drives, and bucket elevator. Additionally, the entire feed system needed to be programmed by CE-CERT before operation could be achieved. The vibrators were mounted on the grating and connected to variable resistors to set the vibration control point (Figure 4-8). Each vibrator, one for sand and one for aluminum oxide, was calibrated for a specific mass flow and programmed into the control software.

Appendix VII shows the locations of key components and sensors. The electrical controls for the hopper screw (SC-801), meter screw (SF-805), and feed screw (SF-806) were installed on the back side of the feed valves

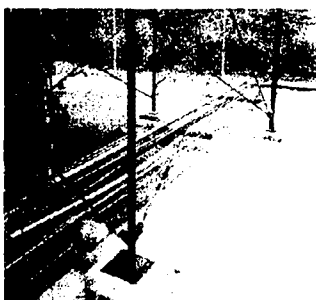
for easy access and close proximity to the drive motors (Figure 4-9a,b). Ladder logic drawings that show the wiring detail were drawn by CE-CERT and are included in Appendix III.

The level sensor, installed in the meter bin, is a capacitive type sensor (Figure 4-9c). When biomass fills the meter bin the capacitance increases with height. During preliminary runs the level signal was too weak to measure. To fix the problem, the surface area of the capacitive sensor was increased. Also, when installing the sensor it was discovered the bend angle was incorrect. CE-CERT modified the bend angle to get it to fit into the meter bin. The capacitive level sensor has been a reliable measure of biomass level.

The bucket elevator shown in Figure 4-9d is used to convey biomass from the ground floor to the top floor, a distance of 7.3 m. Once the precharge hopper is full, biomass overflows back into the hopper bin. The bucket elevator was assembled at CE-CERT and required minimal troubleshooting. The bucket elevator is a reliable method for conveying biomass from the ground floor to the top floor.

CE-CERT tried feeding biomass into the reactor once the feed system was mechanically and electrically functional. Feeding biomass into the reactor was possible because the burner spool piece (B-037) was removed for repair. Biomass could exit the reactor through the 152 mm opening between the burner and the reactor. The plan was to operate the feed system at different speeds and calibrate the mass flow. Unfortunately, the calibration was delayed because bridging problems were discovered in eight locations (Figure 4-10). The problems were located at:

1. Hopper bin.
2. Bucket elevator neck.
3. Return overflow chute connection.



a



b



c

Figure 4-7. Support legs for large storage bin (a). Biomass delivery system (b) and biomass transport into the hopper (c) also are shown.

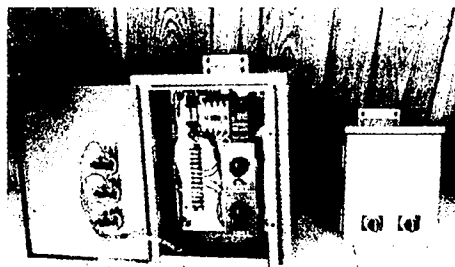


Figure 4-8. Vibrator and electric filter pulse clean heater controls and vibrator controls (left); steam and cooling water controls (right).

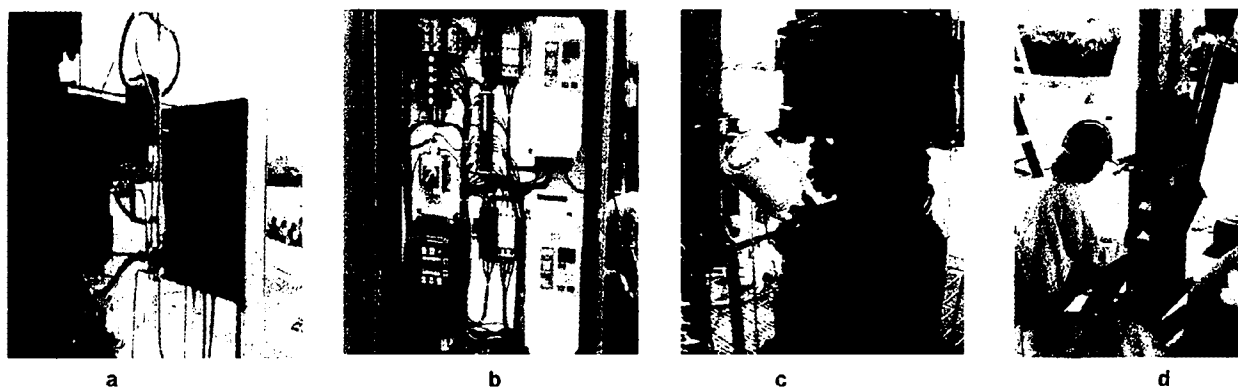


Figure 4-9. (a) Motor drive support; (b) motor drives and feed valve electronics; (c) level sensor installed in the meter bin; and (d) bucket elevator to move biomass from bottom to top of reactor.

4. Precharge hopper.
5. Feed valve.
6. Lockhopper reduction tank.
7. Feed valve.
8. Meter bin.

Each problem required some type of mechanical or electrical design change to get continuous flow through the feed system.

Location 1 was a bridging problem in the hopper storage bin (Figure 4-11). The biomass easily supported an edge and prevented flow into the screw below. If the problem went unnoticed for about one hour, the hopper screw would not have any biomass and the system would run dry. This problem was solved by manually leveling the pile hourly. For commercial autonomous-level operation, large eccentric rotating vibrators would be recommended.

Location 2 was a bridging problem caused by operating the hopper screw at too high a speed. Too much mass was flowing, and it would jam in the small neck at the connection from the bucket elevator and the top of the precharge hopper. To fix the problem the hopper screw rate was reduced as needed.

Location 3 was a bridging problem in the overflow neck on top of the precharge hopper. This problem was fixed by a cleanout air pulse five times at the beginning of a feed cycle. For commercial applications, this modification may not be necessary because of the larger size of the opening.

Location 4 was a bridging problem in the overflow chute connecting the precharge hopper to the hopper bin. The solution was to provide a steady air stream down the chute controlled with the operation of the bucket elevator (Figure 4-12). The air jet was on whenever the bucket elevator was operating. For commercial installations, the bin could be located such that the angle

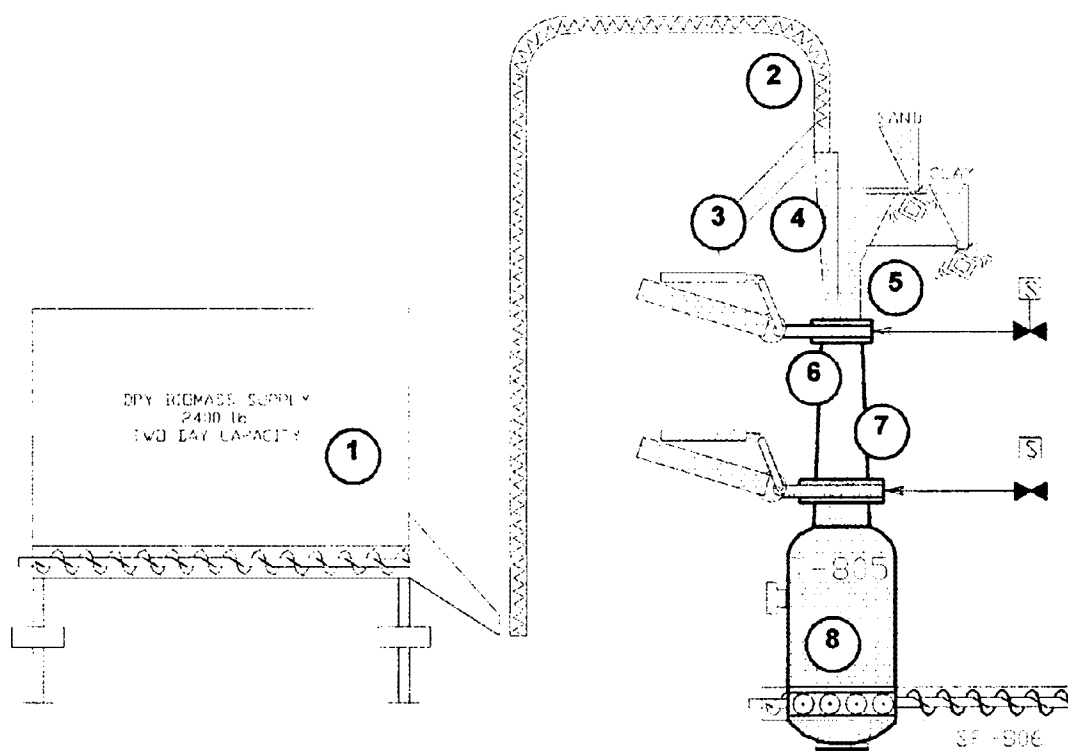


Figure 4-10. Bridging problem locations.



a



b



c

Figure 4-11. Bridging problems in the (a) hopper screw; (b) bridging with feed screw exposed; (c) bridging with feed screw empty thus not feeding biomass.

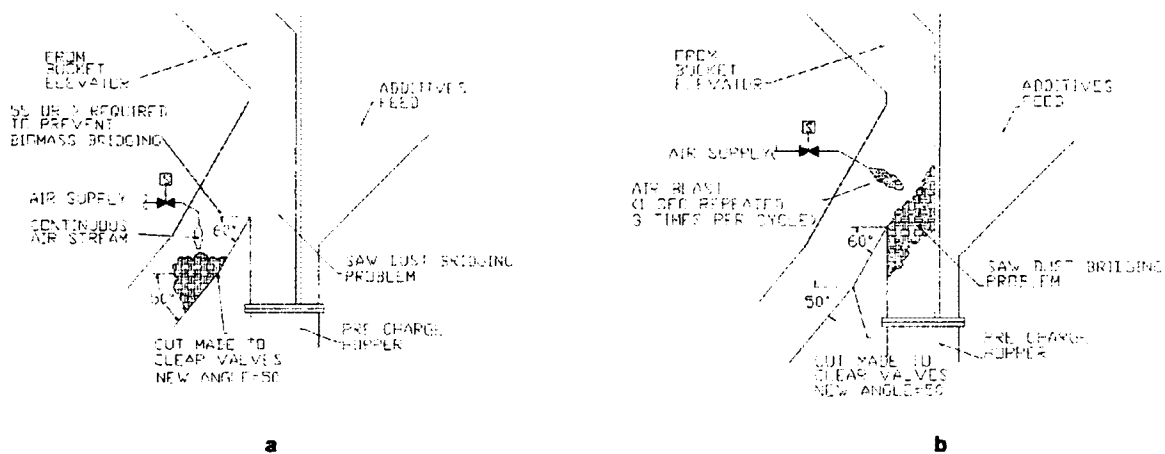


Figure 4-12. Modification made to solve overflow chute bridging: (a) solution for bridging at the neck; (b) solution for bridging in the overflow chute.

from the overfill point to the bin is >55 degrees. A steep angle tends to prevent bridging problems.

Locations 5 and 7 were similar bridging problems that occurred in feed valves FV-839 and FV-840. The large Everlasting valves require a purge gas during closing to prevent any materials from getting caught behind the valve as it swings closed (Figure 4-13). The solution was to incorporate a high-pressure pulse prior to closing both the top and lower feed valves. Location 6 was a

problem with a mechanical liner designed to help biomass flow through the valves. The relief angle on the liner made the final hole too small for biomass to pass through. CE-CERT replaced the liner with a straight section, which solved the problem. For commercial applications, problems 5 and 7 will still exist, but problem 6 most likely will not.

The last bridging problem was in the meter bin, Location 8. Location 8 was the hardest to solve because

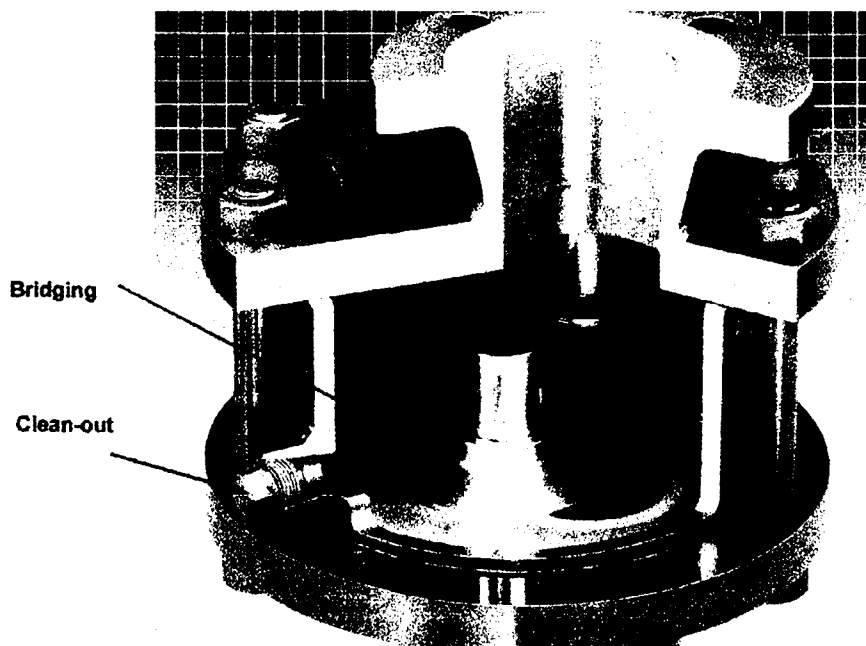


Figure 4-13. Everlasting valve cutaway showing where bridging problems were found.

the problem was not consistent. The problem occurred when the level in the meter bin got too high. The biomass would compact and bridge over the meter screw. The solution was to limit the biomass level to a safe height. In commercial applications, this may or may not be an issue because of the increased cross-sectional area.

The feed screw mass flow rate was calibrated after the bridging problems were solved and the control program was finalized. The mass flow rate was too high at the lowest motor controller setting. There were two solutions: One was to replace the gear box, and the other was to replace the chain and gear drive. The gear drive was the easier and less costly approach. CE-CERT replaced the original 22-tooth gear with a larger 72-tooth gear (Figure 4-14a). The feed was reduced from 40.8 kg/hr. to 19.5 kg./hr. at a command signal of 20 Hz.

The feed calibration was performed after solving all of these feed system problems. CE-CERT calibrated the feed system using a 2-minute sample time because the

theoretical residence time (Dong and Cole, 1996) is two minutes (Figure 4-15). The average mass flow over the sample population was 21.8 kg/hr., with a standard deviation of 1.7 kg/hr. The two-minute mass flow uncertainty was estimated to be 3.3 kg/hr., or 15%. The mass flow is dependent on the bulk density and the packing in the screw flutes, both of which could change without warning. In addition, calibrating the screw feed before and after a test requires labor to remove the bottom reactor piece from the tower. To satisfy the measurement plan for biomass feed rate, load cells were installed under each leg of the hopper bin (Figure 4-14). The change in weight before and after a test will be used as the measure of carbon fed into the system. Unfortunately, the load cells are accurate only for tests greater than 24 hrs. Appendix IV contains details of the sample plan.

The screw feed also was calibrated at different sample time intervals and at different meter bin levels. During 1-minute and 60-minute samples, the uncertainty was estimated to be 30% and 10% respectively. Sample times greater than 60 minutes did not reduce the uncer-

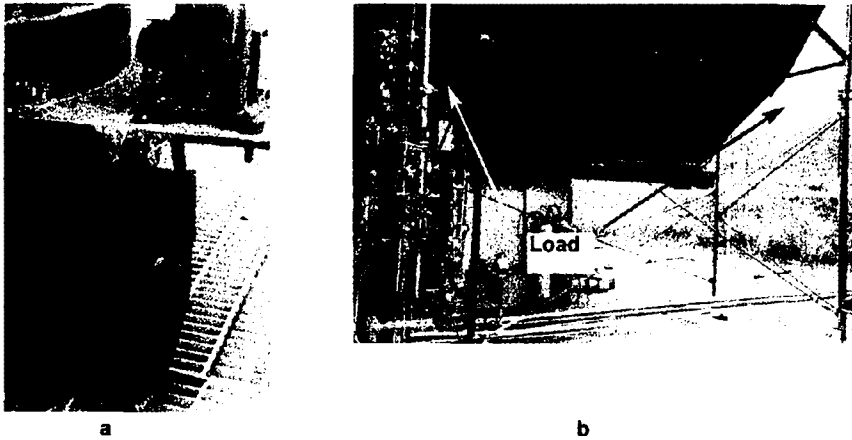


Figure 4-14. (a) Meter bin screw feed gear modifications; (b) load cells located under each leg of the hopper bin. They are used to measure biomass feed into the reactor over a 12-hour period.

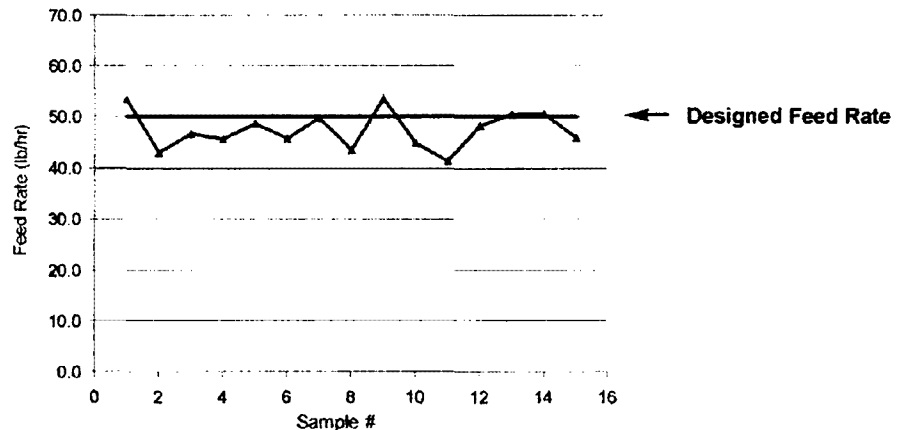


Figure 4-15. Feed system flow rate calibration with 6.4 mm white oak saw shavings (Feed = 25 Hz, Meter = 20Hz, 2-minute collection period and 72-tooth gear).

tainty any further. One-minute flow samples were taken at high, medium, and low meter bin levels (LS-849). The effect due to meter bin level was not significant enough to affect the mass flow into the reactor.

CE-CERT noticed the bottom feed valve was binding on the drive arm after operating the feed system for over 100 cycles. The valve was removed and broken down to investigate the problem. Rust damage was found on the journal bearing, which caused the drive to seize (Figure 4-16). CE-CERT purchased a new drive system and installed it. There have been no more problems with the feed valve since. The manufacturer recommended operating the valves on a routine basis to prevent rust buildup. CE-CERT implemented a preventive maintenance cycle to operate all large pneumatic valves during down times.

4.3 Process Gas Supply

Gas Flow Rate Measurement

Six gas flow rates must be measured accurately as described in the sample plan (Appendix IV). The original design was to use the manufacturer's specification sheet for flow calculations. CE-CERT determined that the manufacturer's estimation had an uncertainty of 50% minimally. CE-CERT performed a 5-point calibration of the orifice plate and flange tap systems over the range of expected flow conditions using a dry gas meter suitable for each flow following ASME standards as listed in the Sample Plan (see Appendix V for calibration curves and tables). Each calibration was completed with nitrogen at pressure and temperature. A summary of the measured uncertainties is listed in Table 4-1.

According to the ASME standard, the gas flow calculations assume temperature, pressure, and differential pressure are being recorded at each orifice plate. The original design did not specify individual temperatures or pressures, but assumed a common temperature and

pressure for all the gases. CE-CERT made the modification by adding 5 temperatures and 5 pressure measurements for CH₄, H₂, CO₂, CO, and the effluent.

The orifice flanges were made of plain carbon steel without any protective coatings. Steel rusts quickly and could damage the orifice plates in a short period. To prevent the rust contamination, the flanges were plated with a 0.0005 in. (12.7 μ m) gold erudite plating.

Steam Flow Metering

An orifice type flowmeter was specified by the design for measurement of steam flow. This is not a recommended sensor type for measuring steam flow because the density can significantly change across an orifice when water condenses due to pressure drop. The solution was to use a 500 mL burette at the inlet to the steam pump and to spot-check the flow of the steam pump during testing. The steam pump is a constant flow pump and should not vary from check to check. Actual system uncertainties will be estimated once more experience is gained with reactor operation. Preliminary flow tests show this method is reliable. During preliminary testing CE-CERT noticed a problem maintaining flow with a back pressure. More investigation is required.

4.4 Hot Gas Filter

Nitrogen Pulse Heater

Preheated nitrogen is used to pulse-clean the high-temperature ceramic filter. The filter element normally operates at 538 °C under steady-state gasification. During gasification the filter elements need to be pulse-cleaned hourly with a high-pressure pulse of nitrogen. The preheated nitrogen is necessary to prevent filter element damage due to thermal shock when pulse-cleaned. Originally, the nitrogen was to be preheated using waste gas from the effluent heat exchanger (HIX-107). This

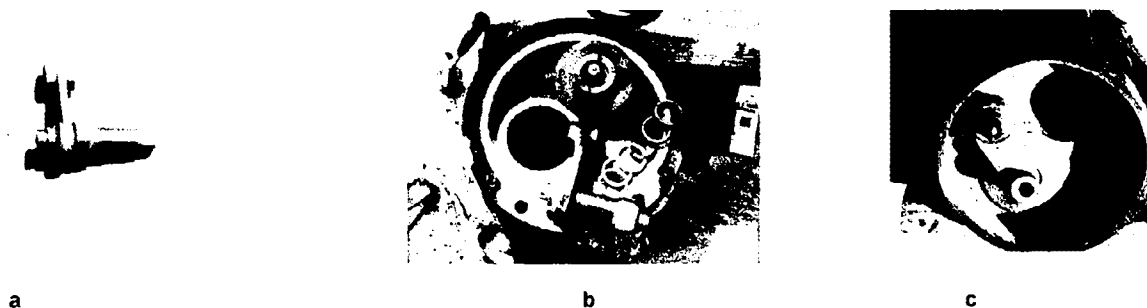


Figure 4-16. Everlasting feed valve drive and assembly: (a) damaged drive torque arm; (b) valve assembly showing seals and valve seat; (c) valve mechanism after reassembly.

was modified when the steam heat exchangers were found to be undersized. The steam is preheated in both HX-107 and HX-108. The solution was a 2 kW band heater controlled by the Cyrano program. The vessel was designed to be 4 feet long by 4 inches in diameter and holds a total of 20 scf when pressurized to 800 psi (Figure 4-17). The pulse heater does operate as expected, but there are problems with the pulsing valves as explained in the subsection below on *Solenoid Valves*.

4.5 Controls

The controls were started by Arcadis and finalized by CE-CERT. This section covers the changes made to the controlling program by CE-CERT.

Bed Height Calculation

Knowing the bed height is necessary to help estimate optimum residence time and understand how the gasifier is performing (Dong and Cole, 1996). Arcadis ran a cold flow model simulating the Hynol facility to determine the expected bed height at different flows and bed material. Analysis by Arcadis concluded that the bed height does not follow this simulation, but rather follows a more theoretical approach (Dong, 1998, personal communication). CE-CERT implemented both methods in the control program, allowing the operator to choose based on operational experience.

Flow Calculation

Flow calculations for CH₄, CO, CO₂, N₂, and H₂ are programmed into Cyrano following the methods out-

lined in ASME P.C. 19.5 (see Sample Plan, Appendix IV). The controller samples gauge pressure, gas temperature and differential pressure at the orifice plates for each of the gases. After each signal is measured the controller converts the units to absolute for flow calculation. The controller then calculates a flow rate based on the square root of the pressure, temperature, differential pressure and molecular weight. The mass based flow rate (normal cubic meters per hour) is then calculated using the orifice calibration constant at a standard condition of 15.5 °C) and 1 atm. The gas flow rate is logged once a minute and updated every five seconds on the computer screen for start up, steady state and shut down operations.

Equations were programmed into Cyrano for the calculation of gas flow for CH₄, CO₂, CO, N₂, and H₂. The program samples the differential pressure, temperature, and pressure at the orifice and calculates the normal differential pressure based on actual temperatures and pressures. The following equations show the calculations for the hydrogen orifice:

$$Q_c = 12.892 \Delta P_a^{0.4291} \quad (8)$$

where

Q_c = Normalized calibration flow at 3.2 MPa and 519.67 °R).

ΔP_a = Actual pressure differential across the orifice plate.

And the final flow is calculated by correcting for the local temperature, pressure, and specific gravity:

Table 4-1. Calibration summary and the actual uncertainty for each orifice plate*. Also included is the expected pressure drop across each orifice plate.

| Entering | Designed Flow (kmol/hr) | Flow SI (Nm ³ /hr) | Flow ENGL (scfm) | Standard Error (scfm) | Uncertainty Measured % | Expected DelP in H2O |
|---------------------|----------------------------|----------------------------------|---------------------|--------------------------|---------------------------|-------------------------|
| CO | 0.1612 | 3.61 | 2.12 | 0.00622 | 1.00% | 1.042 |
| CO2 | 0.0983 | 2.2 | 1.29 | 0.0115 | 1.00% | 1.533 |
| CH4 | 0.0449 | 1.01 | 0.592 | 0.0066 | 1.50% | 0.45 |
| H2 | 1.771 | 39.7 | 23.4 | 0.462 | 2.00% | 4.00 |
| N2 | 0.1711 | 3.83 | 2.25 | 0.0057 | 1.00% | 4.67 |
| H2O | 0.2859 | 11.5 | 6.77 | n/a | in progress | n/a |
| Exiting effluent | 3.056 | 68.45 | 40.3 | 0.240 | 1.00% | n/a |

* Flow calibrations are based on a STP pressure = 14.696 psi (1 atm) and temperature = 60 °F (15.55°C).

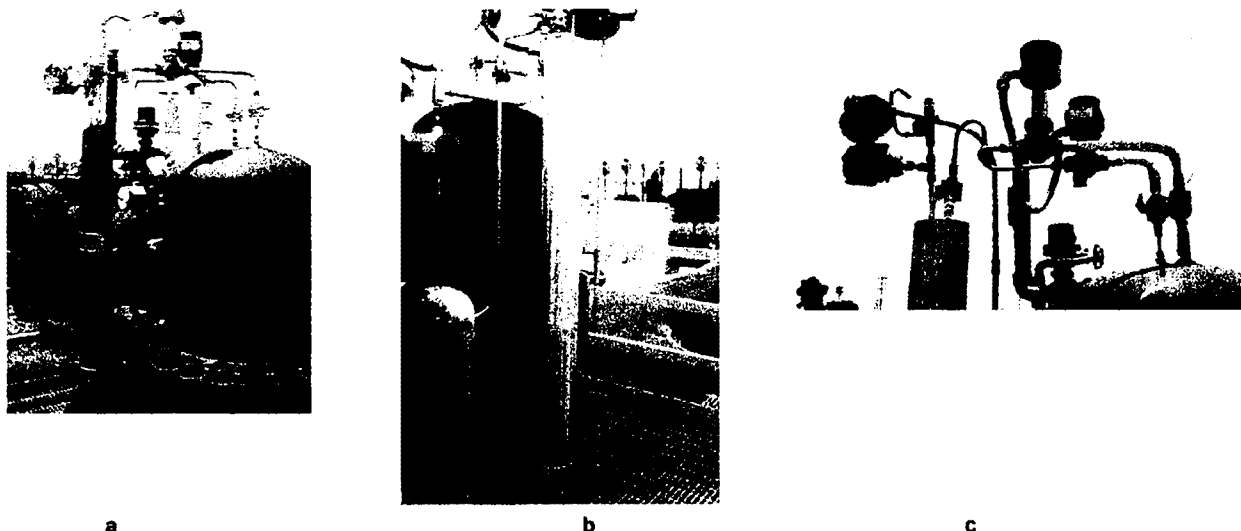


Figure 4-17. Heater pulse cleaning system for the hot gas filter.

$$Q_a = Q_c \sqrt{\frac{T_c P_a SG_a}{P_c T_a SG_c}} \quad (9)$$

where

Q_a = Actual flow rate in (scfm) corrected for pressure, temperature, and specific gravity.

T_c = Normalized calibration temperature (519.67 °R).

P_a = Actual pressure at the orifice flange tap in psi units.

SG_a = Actual specific gravity of the gas flowing through the orifice.

P_c = Normalized calibration pressure (3.2 MPa).

T_a = Actual temperature of the gas upstream of the flange tap °F units.

SG_c = Specific gravity of calibration gas (Hydrogen was used for H_2 flow and nitrogen was used for CO , CO_2 , N_2 , and CH_4 flows).

Burner System

Since the BMS was not functional, all the controls for this portion were removed from the control program and the program was modified to reflect the new safety interlock and process requirements to start, monitor, and

stop the burner. The program prevents operation of the burner if an alarm is activated. Also, the controller calculates the air-to-fuel ratio of the gas going through the burner.

Water and Steam Pump

No remote starting systems were designed for the steam pump and water pump. They are necessary to start the steam pump at a desired process temperature. Easy starting of the steam pump and cooling water pumps is necessary for the safe operation of the facility. The starting of these pumps is remotely controlled in the control room by either manual or automatic modes.

Nitrogen Pulse Heater

The nitrogen pulse preheater controls include manual and automatic controls. The start, stop and desired set point are controlled by the computer or manually at the heating element. A proportional, integral and derivative (PID) controller was programmed in Cyrano, which ramps up the temperature to the desired set point.

Feed System

The feed system automation was programmed in OPTO 22. There were many revisions to control logic due to the problems mentioned earlier. The final flow block diagram is shown in Figure 4-18. First, the feed system is manually started and the feed system checks the level meter (LS-498). If the level is greater than 6 mA, the feed cycle is initiated; otherwise, the program waits for the level to drop below 6 mA. Once the cycle starts, the

nitrogen purge flow is checked. If the flow is too low (less than 2 inH₂O) the operator is instructed to open FCV-404 before the cycle will continue. The nitrogen flow is used to keep positive pressure in the meter bin, which prevents heat from flowing into the bin. When the lower feed valves open, there is a brief inrush of gas into lockhopper LH-801. Without nitrogen flow, hot gases from R101 would be drawn into the meter bin, eventually causing mechanical and process damage.

Once the N₂ flow is set >2 inH₂O, the additives are combined with the biomass in the precharge hopper. The program then checks to make sure the bottom valve FV-840 is closed before depressurizing. If the valve is not closed, the controller closes the valve. Each time FV-840 or FV-839 is opened or closed, the time out and stop and alarm blocks are activated. If the valve does not do what it was supposed to, an alarm is sounded, the operator sees an error message, and the plant is put in standby mode.

After successful indication that FV-840 is closed, the lockhopper LH-801 is depressurized. Once the pressure in LH-801 is less than 34.5 kPa, the top feed valve (FV-839) is opened. Biomass drops into LH-801 while a pulse air blast cleans out the neck area #2 (see Figure 4-10). The valve (FV-839) is closed and pressurized through FV-839 cleanout port connection. Once the pressure is \geq reactor pressure (PT-804), the bottom valve is opened. Biomass drops into the meter bin. The feed level should increase by at least 0.5 mA. If the level remains unchanged, the operator receives an error message, and the feed system is terminated until reset.

After biomass drops into the meter bin, a second nitrogen blast cleans out the bottom valve (FV-840). The valve closes and the cycle checks the level. If the level is greater than 13 mA (high level), the cycle is ended. Otherwise the level is still less than the high level mark, and the cycle repeats itself after timer KS-840 expires (90 seconds).

Each feed cycle takes approximately 90 seconds from start to stop. Between each feed cycle there is a 90-second wait time to fill the precharge hopper. During steady state testing, it was estimated the feed cycle takes 15 minutes to fill the meter bin with a 5- to 10-minute wait between ended cycles.

4.6 Cooling System

The cooling system includes a cooling tower, cooling pump, and an effluent gas heat exchanger. CE-CERT

provided a drip type naturally aspirated water cooling tower. It is well oversized for the process and is expected to be adequate during steady-state gasification testing. The water pump provided for the project was only ¼ hp (186 W) and undersized for the flow needs of the process. CE-CERT installed an available 4 hp (3 kW) cooling pump that has been working error-free.

The cooling system also has an 24.4 m heat exchanger that extends from the top of the tower to the flare stack. It was designed to bring the final effluent temperature down to 93.3 °C and to preheat the steam before it enters the main heat exchanger vessel. (Figure 4-20).

4.7 Solenoid Valves

The original design specified solenoid operated gate valves designed and manufactured by Atkomatic. During shakedown, five of the fifteen valves have been troublesome. Two have been replaced and currently the other three are being bypassed. CE-CERT recommends replacing the valves with pneumatic valves because of reliability and longevity.

4.8 Exit Flare Stack

The flare stack came with a 2.1 m extension and no mounting hardware. According to local code, the flare had to be 4.6 m above the working surface. CE-CERT modified the system with a 2.5 m extension and guide-wire support anchored to the concrete pad (Figure 4-21). The electrical controls were installed by CE-CERT. The flare starts manually, but has an automatic shutdown and external alarm to the operator for safety. The flare stack has been successfully operated.

Main Heat Exchanger HX-205

The purpose of the main heat exchanger is to preheat inlet gases before they enter R101. The heat exchange takes place between the hot effluent exit gas and the cool simulated recycle inlet gas. The original heat exchanger was made by Arcadis from porous ceramic block. Ceramic was chosen due to expected 760 °C effluent gas temperatures.

The problem was that the ceramic heat exchanger would allow gas to transfer from the cool side (higher pressure) to the hot side (lower pressure). The pressure difference is the drop in pressure in the system. The pressure drop is determined from the resistance to flow through the heater, burner, distributor plate, three meters of biomass, a cyclone, and the high pressure filter before it becomes

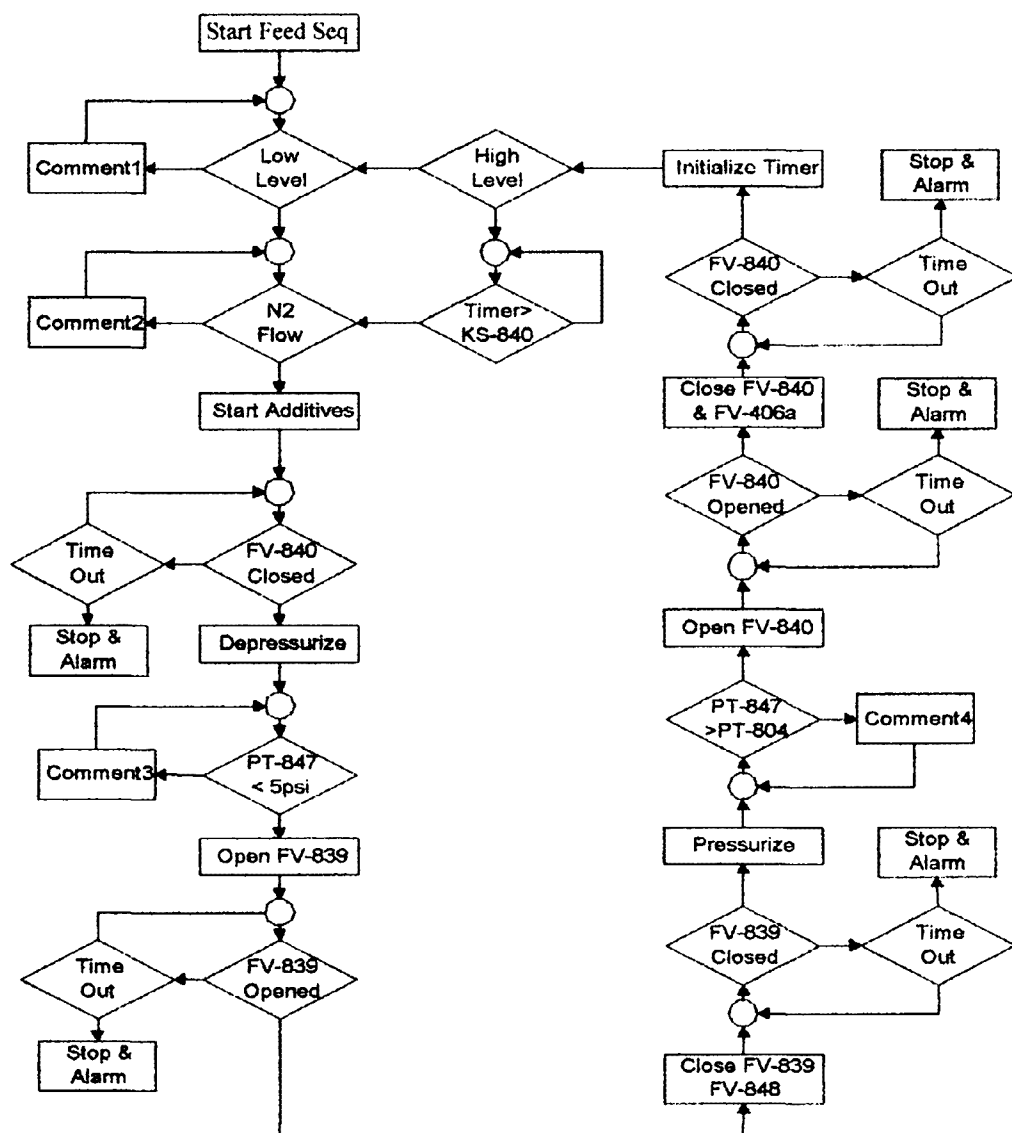


Figure 4-18. Feed system final version logic for the lock hopper high pressure design.

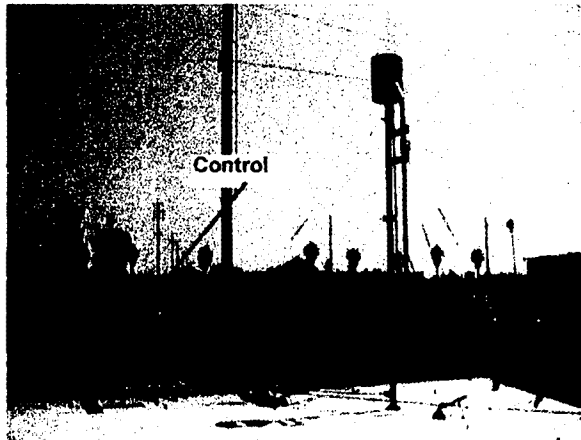
the hot effluent gas. The pressure drop is expected to be around 34.5 kPa. A test rig was set up (Figure 4-21) to evaluate the heat exchanger performance. The goal was to measure how quickly the gas would leak into the process side with one end of the heat exchanger plugged and the other side pressurized to 34.5 kPa. The leak rate was less than $\frac{1}{2}$ second thus requiring HX-205 to be redesigned and installed. The new design is 55 ft of 12.7 mm x 0.889 mm Haynes Alloy 630 tubing coiled with a radius 127 mm and a gap of 1.59 mm between each pair of coils. The heat exchanger will be evaluated once steady state gasification is achieved.

4.9 Sample System

The sample system is shown in Figure 4-22 and described in detail in Appendix IV. The goal of the sample system is to measure in real time CO, CO₂, CH₄, and H₂ while collecting deposits on four filter assemblies and removing water through a 689.5 kPa, 1.67 °C cooling system. The expected moisture of the analyses is 2000 ppm. From the composition and flow data, it will be possible to characterize when the plant reaches steady state and to calculate approximate carbon conversion efficiency, thermal efficiency and mass balance.



Figure 4-19. Effluent gas heat exchangers (HX-109, 110a, and 110b), a tube within a tube.



a

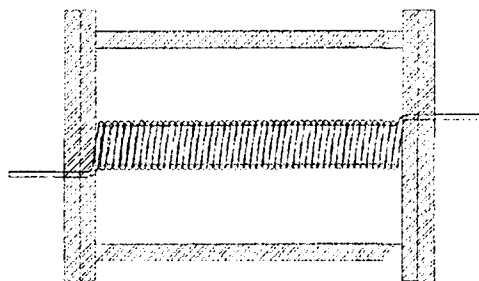


b

Figure 4-20. (a) Flare stack, extension, and guide-wire support; (b) electrical controls and valves.



a

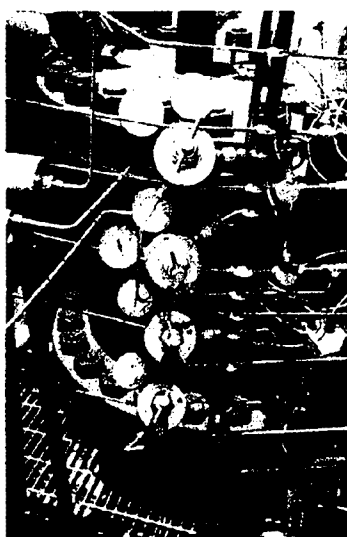


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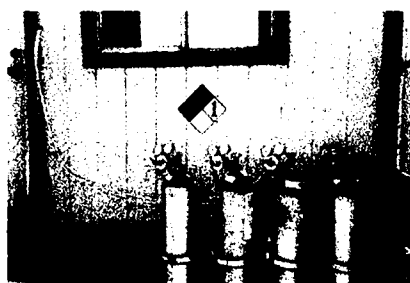
Figure 4-21. (a) Heat exchanger HX-205 leak rate test setup; (b) HX-205 redesign.



a



b



c

Figure 4-22. High-pressure sample system: (a) high-pressure impingers submersed in ice/salt mixture (-20.6°C) during testing; (b) array of pressure regulators prior to going into dry gas meters and after impingers; and (c) calibration gases for continuous analyzer.

5. Preliminary Results

5.1 Test 1: Air Gasification

Test Goals: The goals of tests 1a and 1b were to demonstrate reliable operation of the burner, feed system, heater, and bed height pressure drop. Secondly CE-CERT also hoped to achieve 1472 °F (800 °C) bed temperatures to demonstrate optimum biomass gasification.

The locations of thermocouples and valves listed below are shown in the Diagrams provided in Appendix VII of this report.

Result Summary 1a

The burner was unreliable at first, but once burner temperature TE-020 was > 1500 °F (816 °C) the burner was easy to stop and start. The feed system ran reliably except for a bridging problem in FV-840. The bridging problem caused a gas leak through FV-840 and FV-839. The leak caused heat to flow into the feed system meter bin, thus overheating feed screw TE-808. At the same time the process filter (F-104) clogged; this was indicated by a large (>50 psi, 344 kPa) pressure differential between inlet and exit pressures (PT-030 - PT-823). As a result of these problems, the ideal bed temperatures and bed height pressure drops were not achieved and gasification was not performed.

Test Setup and Operation

12/7 Primed R101 bed with 26 liters of sand (static bed height of 1.3 m). Tried to preheat the reactor with the electric heater (H-036) to 204 °C as necessary to prevent water condensing during burner operation. The heater capacity was not sufficient to preheat the reactor to 204 °C; thus, the burner was started even though water condensation would occur inside R101. The burner would not start because of a problem with the spark rod igniter. Shutting down until burner operational.

12/10 Same static bed height. Tried starting burner, but modified spark rod igniter failed again. The method being used is not reliable. A new design is necessary. While fixing the spark system, CE-CERT modified the air and natural gas plumbing to make start-up safer and quicker.

12/16 Designed new spark system that worked reliably on the bench and in the reactor. Operated burner until TE-809 was 427 °C.

12/17 Cycled the feed system valves as a safety check prior to starting the feed system while waiting for the temperature at TE-809 to increase.

12/18 Operated feed system after TE-809 reached 427 °C. The feed system ran reliably except for a bridge problem in tank T-805. The bridging problem caused a gas leak through FV-840 and FV-839. The leak caused heat to flow into the feed bin, thus overheating the feed screw TE-808. At the same time the process filter (F-104) clogged, as indicated by a large (>50 psi) pressure differential between inlet and exit pressures (PT-030 - PT-823). As a result of these problems, the ideal bed temperatures and bed height pressure drops were not achieved. Shut down system and started purging with nitrogen.

12/19 Purged reactor with nitrogen.

End of Gasification Test 1a

The automation of the feed system was the main success from test 1a. Figure 5-1 shows a typical automation profile for the high-pressure feed system, as per the design modification. Once the level signal (LSL-849) goes below 6 mA, the feed cycle is started. First the lockhopper LH-801 is pressurized from ambient to reactor pres-

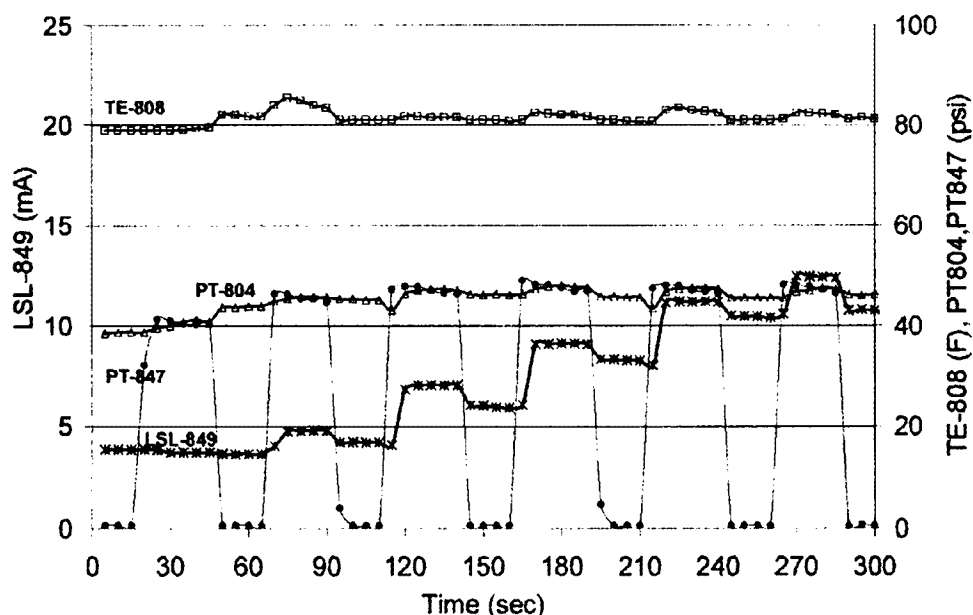


Figure 5-1. Automated operation of the feed system during gasification test 1a.

sure (PT-804) + 34.5 kPa. The excess pressure is used to help push the biomass into the meter bin (T-805). If the pressure is in excess of 68.9 kPa, the extra pressure will prematurely open the bottom valve (FV-840) and prevent the cycle from completing. Once the pressure (PT-847) in the lock hopper (LH-801) is 34.5 kPa greater than the reactor pressure (PT-840), the bottom valve opens after a determined delay and the biomass drops into the meter bin. The added biomass to the meter bin can be seen by the rise in LSL-849. The completion of a cycle is noted by PT-847 going from reactor pressure (PT-804) down to ambient pressures. Also note the constant drop in LSL-849 between cycles as biomass is constantly fed into the reactor (R101). The delay between cycles is necessary to fill LH-801 with biomass, kaolinite and sand.

Unfortunately, a bridging problem occurred at the biomass feed valves. The bridging was due to a human error, not a process control error. FV-427 was not opened as listed in the preliminary startup procedures. As a result of not opening FV-427, biomass collected on the back side of the lower feed valve (FV-840), preventing the valve from fully closing. Because the valve was not fully closed, gas leaked past the valve seat during each feed cycle. The gas leak through the valves caused a rapid overheating of the feed screw TE-808. Once the feed screw temperature exceeded 204 °C, the plant was shut down and the problem was investigated.

The filter also clogged during test 1a. According to the filter designer, after gasifying/combusting biomass the filters need to be purged with hot air to burn off any residual carbon. Purging with hot air would be possible by operating the burner for 2 to 3 hours after gasification. Because of the rapid increase in TE-808, the reactor was shut off and not brought down slowly with the burner. CE-CERT believes shutting off the reactor without purging the filters with hot air is what caused the filters to clog. To fix the problem, the manufacturer suggested burning off the residual carbon with air at 315 °C. CE-CERT rented an industrial propane heater and burned off the residual carbon from the filters. The heater was installed at the base of the filter with access through tank T-104. CE-CERT confirmed the filters were cleared by successfully running a simple pressure test. A filter cleaning SOP has been established for the future.

One of the more time-consuming tasks was to get a reliable spark at the center of an 457 mm pipe through a 6.4 mm hole inside a vessel at 7 atm. The original design as described in the Burner Management section solved the problems initially, but after extended use that modification became unreliable. During operation the spark rod and ground moved from thermal expansion and gas velocities. If the gap were more than 3.2 mm, the spark-er would not work. In addition, adjustments to the gap were made 61 cm into a dark 25.4 mm hole, which made it difficult to set the correct gap size. The modified

design had the spark rod and ground in the same housing. This design would have worked, but the high-voltage spark found an easier path through the insulating seal of the high-pressure pass-through. The next design took advantage of the same concept of providing the spark and the ground in the same unit, but with a better pressure seal. The high-pressure pass-through manufacturer had a special seal material available, but the cost was in excess of \$5,000 each with a minimum order of 10. Instead, CE-CERT modified an off-the-shelf spark plug to serve as the burner spark system. It proved to be very reliable and simple to fabricate.

Result Summary 1b

The burner operated reliably every time. Ideal bed temperatures were achieved and air gasification was noticed, but with low CO and CH₄ concentrations. The electric heater was damaged again and the feed system was jamming consistently. After removing the burner spool piece, large agglomerations were found surrounding the feed system inlet to R101.

Test Setup and Operation

1/5/99 The bed is still primed with 26 liters of sand minus any losses. Turned on electric heater to 20%, 40% then 60%. Started burner after TE-020 was >400 °F (200 °C).

1/6/99 Turned feed system on once TE-809 reached 427 °C. Feed system set at 22/7 kg/hr., 1.13 kg/hr. kaolinite, 1.13 kg/hr. sand and an air flow set at 22.1 Nm³/hr (sub-stoichiometric combustion by 1/3). The burner and nitrogen flows were also turned off. The reactor temperatures were very unstable. The feed system was jamming every 10 minutes. Tried adjusting the air flow to keep temperature stable. The feed system was toggled on and off every 5 to 15 minutes to clear jamming problem.

1/7/99 Because the natural gas storage capacity was below the needed supply pressure for the natural gas burner heating, the reactor was temporarily shut down to recharge the compressed cylinders to 24.8 MPa. Turned burner back on to attempt gasification again. Waiting for TE-809 to reach 427 °C.

1/8/99 Temperature of 427 °C was reached. Before starting up feed system, added sand to increase the bed height. Added an additional 20 liters of sand at 06:00. Now the static bed height is 2.5 m minus any losses.

1/9/99 All attempts to gasify were well below ideal. Shutting down reactor to investigate problems with the feed system and the reactor gasification area.

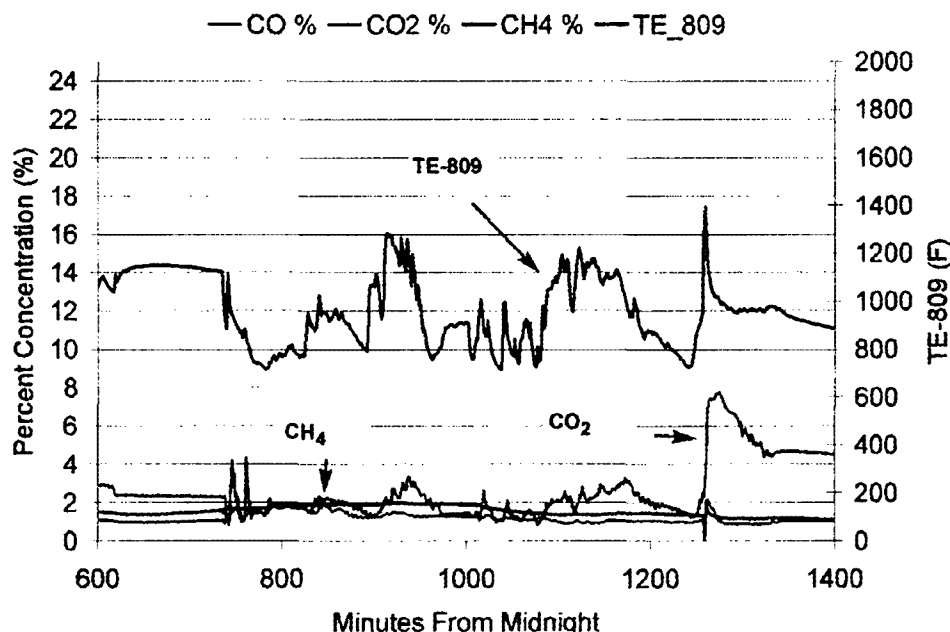


Figure 5-2. Gasification product concentrations for test 1b, January 8, 1999.

End of Gasification Test 1b

Even though ideal gasification was not achieved, there were some signs of gasification. Ideal gasification should yield CO and CH₄ percentages around 10 to 15%. The best results from test #1b were 2% CO, 0.5% CH₄, and 9% CO₂ (Figure 5-2). The low CO and CH₄ concentrations and the high CO₂ concentration indicate more combustion than gasification was occurring. One reason for the poor gasification could be the problem with agglomeration. The agglomeration plugged the entire reaction area, thus preventing proper fluidization.

The feed system operated with no bridging problems, but there was an operational problem to consider for future designs. The biomass that remains in the precharge has a tendency to get wet during idle months. Future designs need to accommodate weather protection, and operational designs need to purge out the biomass prior to shutdown. Our SOPs (Appendix VI) include five feed system cycles during shutdown and a pretest check for all chutes to be clean and free of any obstructions.

A second problem was noticed with the feed system. After about an hour of gasification, the main feed screw SF-806 motor would overload and stop. CE-CERT initially thought the problem was due to a mechanical interference with the feed screw and shaft housing. After removing the bottom vessel to inspect the feed area,

large stonelike agglomerations were found (Figure 5-3). In Figure 5-3a, notice the blockage filling the entire reaction area of R101 just above the feed system. Figure 5-3b shows the agglomeration pieces that dropped out of R101, coming to rest on the burner B-037. Figure 5-3c and d show R101 and B-037 after being cleaned and ready for reassembly.

Operating bed temperatures were achieved during test 1b (Figure 5-4). Unfortunately, the problem in achieving steady-state gasification prevented stable uniform bed temperatures. Notice the reactor temperature (TE-809) on January 6 between 1:00 and 9:00 varied by approximately 315 °C. The sudden increases in temperature were noticed after toggling the feed system back on after it jammed. It is believed the agglomeration problem was a result of the fluctuating temperatures and/or a poor choice of bed materials. Local hot spots could have gotten hot enough to fuse the sand.

During maintenance checks CE-CERT found all the heating elements damaged. The damage was due to poor support for the heater elements. According to the manufacturer, the elements need to be loosely supported from horizontal movement every 304 mm. The type of support installed was rigid and in contact with the elements. The modified design (Figure 5-5) used advanced powder metal (maximum temperature 1482 °C) for a support rod and 10 ceramic disks with a 6.4 mm gap for the loose support. This system also failed, as discussed in test #2 results below.

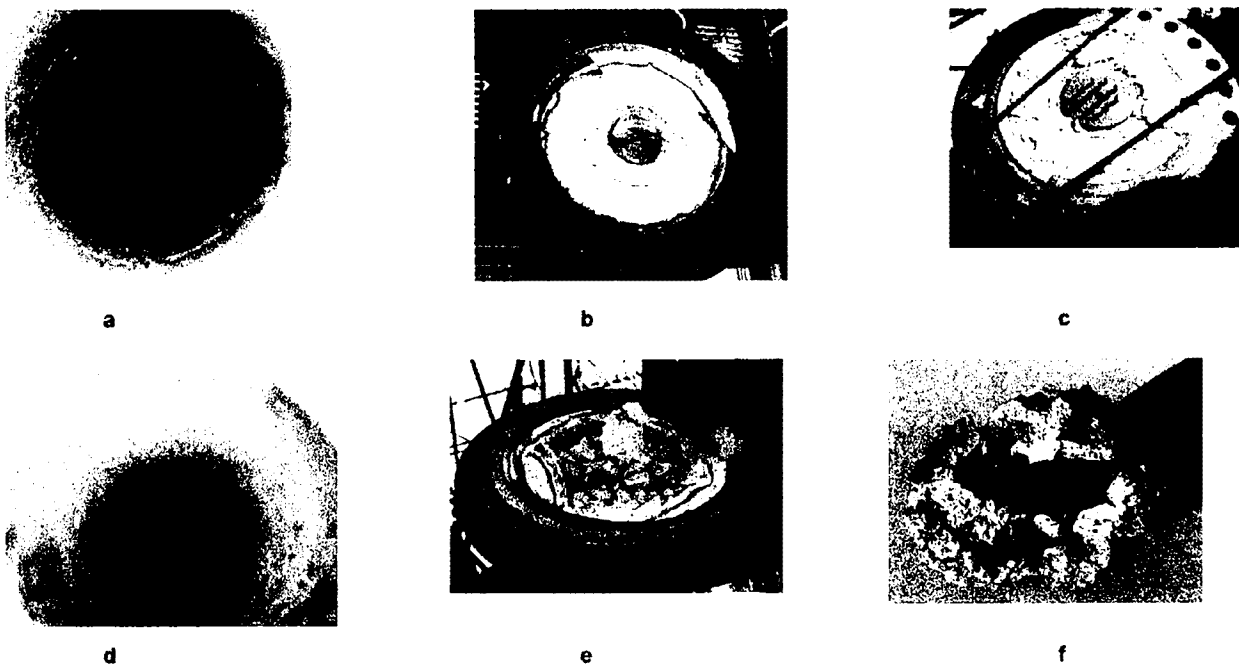


Figure 5-3. Agglomeration results after air gasification tests at 5 atm and 13 scfm air with 50lb./hr. biomass. Bed temperatures reached 982 °C, but were not consistent.

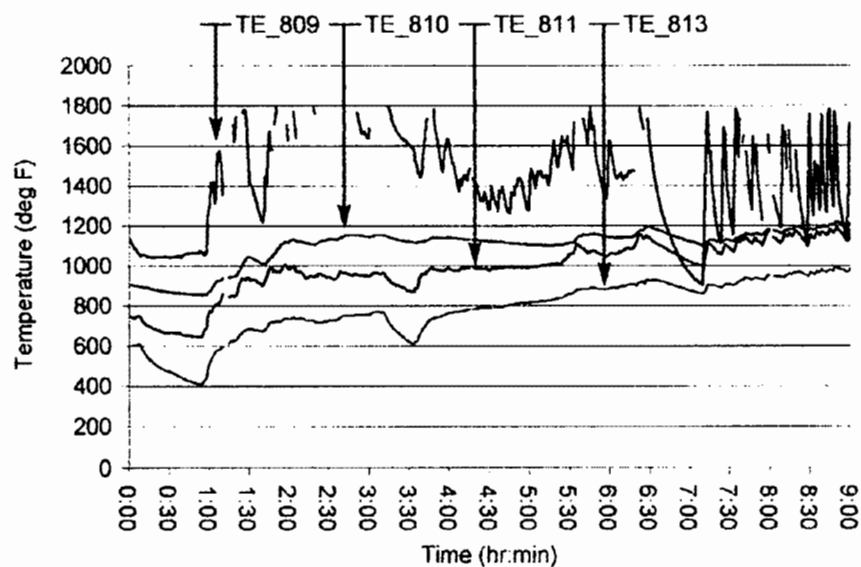


Figure 5-4. Bed temperature profile from the gasification area for test 1 on January 6, 1999.

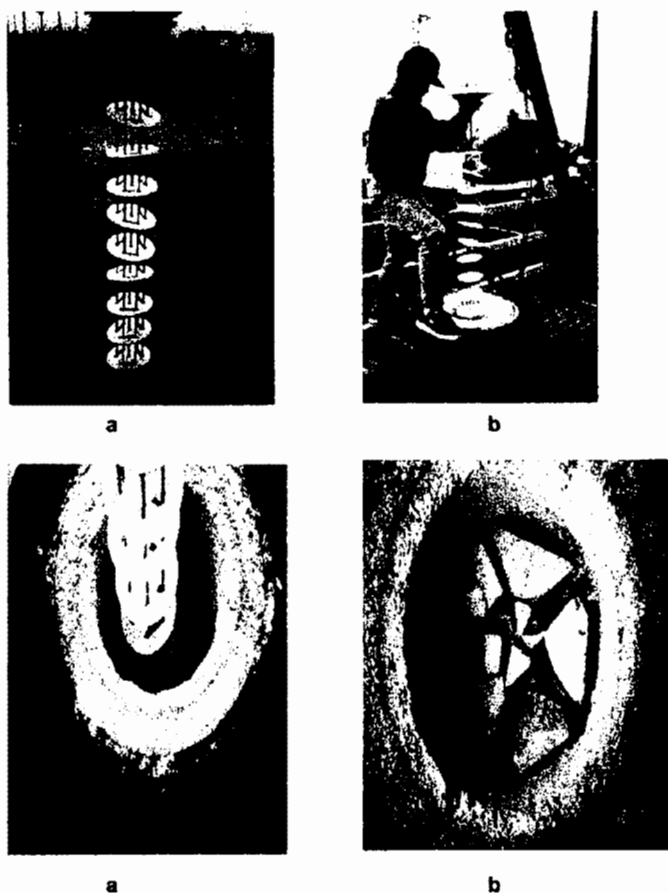


Figure 5-5. Installation of new elements and supports: (a) heater element assembly; (b,c) element installation into heater vessel (H-036); and (d) final assembly with loose packing to prevent shorting.

The agglomeration problem is thought to be due to either melting the bed material or an alkali formation with the sand fluidizing media and potassium and sodium in the biomass. Alkali formation is a common problem with coal and biomass gasifiers. If the problem is from alkali formation, one solution is to use an alkali getter such as aluminum oxide. Unnasch (1996) recommended using kaolinite for the Hynol process at 5% by weight with the feed system as designed into the controls. If the problem is due to a poor choice of bed materials, other sands could be investigated.

5.2 Test 2: Air Gasification

Test Goals: The goals of this test were to demonstrate reliable burner operation, heater operation, and to achieve operating bed temperatures. Once bed temperatures were achieved, CE-CERT would attempt to fluidize the bed and demonstrate hot ash removal cycles with a sand/kaolin mix. After successful ash removal cycles were completed, CE-CERT would then attempt biomass gasification, with the bed primed with 2.5L sand and 0.5L kaolinite.

Results Summary

Reliable burner and heater operation were demonstrated. There was no damage to the heater elements. Bed temperatures of 800 °C were achieved. The ash removal cycles were successful at operating temperatures. The

agglomeration problem still exists, but the severity was much less than in test 1a and 1b.

Test Setup and Operation

3/30/99

08:30 Started electric heater.

10:25 Started burner easily and operated until the reactor bed TE-809 reached 427 °C.

3/31/99

02:50 TE-809 at 427 °C. Completed 20 successful ash removal cycles. For each test, 2 liters of sand and 0.5 liters of kaolinite were added, but only 2 liters of mixture was removed from the ash cycles. Each ash cycle removed an average of 0.3 liters of mixture.

08:00 Shut down system to prime bed with 2.5 liters of sand and 0.5 liters of kaolinite, which represents a 152 mm static bed height. Slowly pressurized the system to 25 psig (172 kPa) and set the air flow to 0.3 Nm³/hr. Successfully demonstrated an ash removal cycle before starting the feed system. Ran the feed system for 30 seconds to add approximately 0.23 kg of biomass (Figure 5-6).

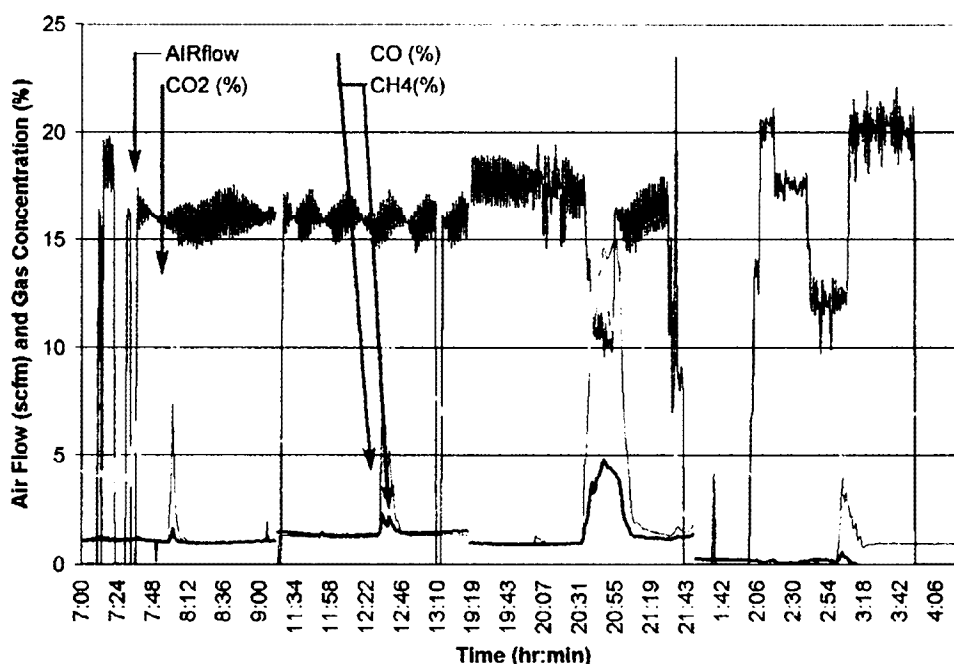


Figure 5-6. Gasification attempts, March-April 1999.

08:15 One aspect critical for gasification facilities is ash removal. The facility was designed with an upper and lower ash removal system. The system was designed to operate once per hour, removing 1.4 kg/hr char and 0.3 kg/hr sand. Completed 5 successful ash removal cycles.

12:20 Primed bed with 2 liters sand and 0.5 liters kaolinite. Slowly pressurized the system to 25 psig (172 kPa) and set the air flow to 0.3 Nm³/hr. Successfully demonstrated an ash removal cycle before starting the feed system. Ran the feed system for 1 minute to add approximately 0.45 kg of biomass (Figure 5-6).

12:45 Completed 5 successful ash removal cycles.

13:45 Purged process filter and primed natural gas and nitrogen storage tanks for a longer gasification run.

20:30 Primed bed with 2 liters sand and 0.5 liters kaolinite. Slowly pressurized the system to 25 psig (172 kPa) and set air flow to 0.3 Nm³/hr. Successfully demonstrated an ash removal cycle before starting the feed system. Ran the feed system for 20 minutes to add approximately 17 lb (7.6 kg) of biomass (Figure 5-6).

21:00 Noticed large pressure differential (>50 psig; 345 kPa) across the process filter. Pulse-cleaned filters and turned burner back on to provide hot air to clean out process filters.

22:30 Process filters pressure drop cleared.

4/1/99

02:13 Started burner to bring TE-809 back up to 427 °C.

02:35 TE-809 >427 °C. Slowly pressurized the system to 25 psig (172 kPa) and set the air flow to 13 scfm (22.1 Nm³/hr). Successfully demonstrated an ash removal cycle before starting the feed system. Ran the feed system for 10 minutes to add approximately 4.5 kg of biomass (Figure 5-6).

03:00 Temperature TE-809 flared up to 699 °C. Tried to perform an ash removal cycle, but it was not successful. The process filter also seemed to be clogged because of the large pressure differential across the filter.

05:00 The process filter was cleaned, but the ash removal system is still clogged. Shutting down to fix the problem.

14:00 Removed bottom valves to inspect ash removal passage. Small agglomerations were found inside the ash removal passage. Cleaned out passage and visually confirmed reaction chamber was free of large agglomerations.

End of Gasification Test 2

Test #2 confirmed the stable operation of the feed system, burner, and the electric heater. In addition, two new cycles were successfully demonstrated: the ash removal cycle and filter pulse-clean cycle. The burner was easily started after preheating with the electric heater. Once TE-809 was > 427 °C, over 20 successful ash removal cycles were performed. An ash removal cycle removes ash, sand and kaolinite from the bottom of the reaction zone through a 25.4 mm tube. The reactor was primed with 2.5 liters of sand and 0.5 liters kaolinite to give a static bed height of 152 mm. It would usually take eight cycles to remove all the sand and kaolinite, which is an average of 0.3 liters removed per cycle. One thing noticed about the ash removal cycles was 3 liters of mix was added, but only 2.5 liters of mix was removed. Because the kaolinite is so light in comparison with the biomass, it may be elutriating out of the biomass and coating the reactor walls. This doesn't cause any operation problems, but it does prevent the kaolinite from absorbing alkali from the biomass during gasification. The next test, test #3, will be performed with limestone as the alkali getter.

Gasification was attempted at 08:00, 12:20, 20:30 and 02:20 on March 31 and April 1, 1999, as shown in Figure 5-6. The corresponding bed temperature and pressure drop profiles are shown in Figures 5-7 and 5-8. During the gasification runs, the feed system was set at 22.7 kg/hr. and air was added at a flow rate of 22.1 Nm³/hr to attempt sub-stoichiometric combustion. The 30-second and 1-minute tests at 08:00 and 12:30 showed no sign of temperature increase, but there was a significant increase in CO and CO₂. The 10-minute and 20-minute runs at 20:30 March 31 and 02:20 April 1 showed an increase in bed temperatures, and CO, CH₄ and CO₂ concentration. The CO, CH₄ and CO₂ concentrations were 15%, 4.8%, and 15% respectively at the peak performance. These results are better than previous tests, but still not high enough for achieving the expected results.

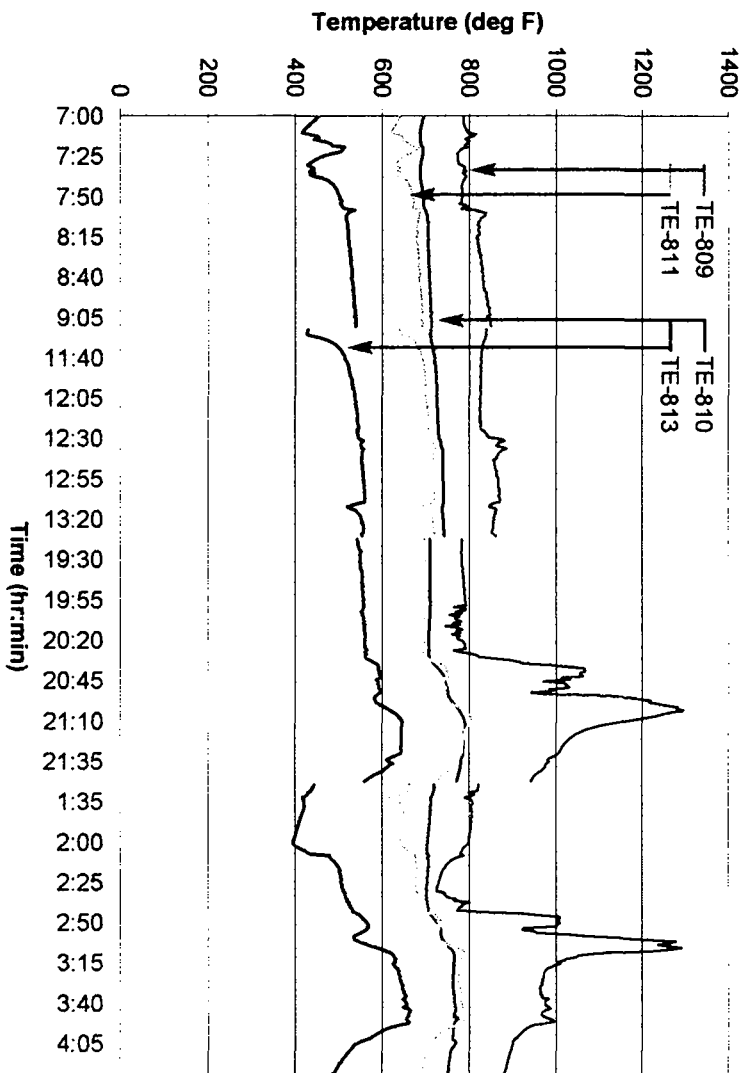


Figure 5-7. Gas temperatures, March-April 1999.

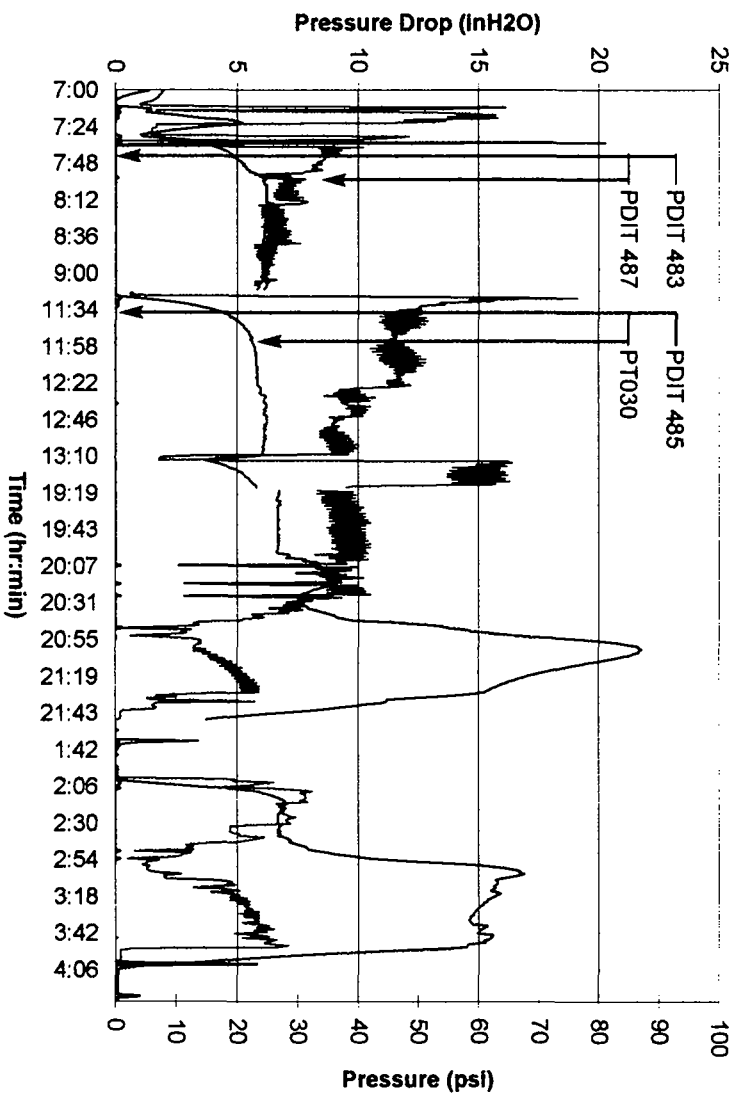


Figure 5-8. Pressure drop, March-April 1999.

The ash removal process was successful before gasification, but there were problems after gasification. During the 20-minute and 10-minute gasification test, the ash removal passage was clogged and needed manual cleaning to break up the blockage. The blockage was removed and looked like small agglomerations similar to those in test #1. In addition, there was a sharp rise in pressure drop across the process filter that indicated clogging during these tests. The agglomeration problem may be solved by using a different alkali getter as performed in test #3, or using a different bed material.

During maintenance checks, CE-CERT found all the heating elements damaged except for one set. The center rod support failed due to excessive temperatures (Figure 5-9). The support rod was designed to operate in temperatures as high as 1204 °C, but to melt like it did the temperatures would have been in excess of 1482 °C (1480 °C). According to the manufacturer, the low density gases must not carry away the heat very well, leaving the support rod in a high-temperature zone not measured by the thermocouples. A third design (Figure

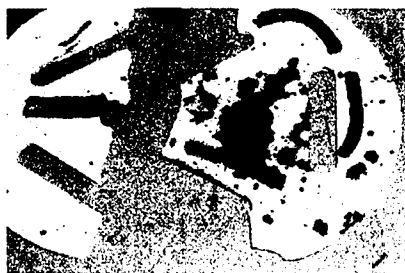
5-10) uses silicon carbide for the main support and similar ceramic spacers. The new silicon carbide support rod is designed to operate in temperatures as high as 1649 °C. To prevent future damage to heater elements, more conservative start-up and shut-down procedures are put in place. Direct element temperature is being monitored.

5.3 Test 3: Biomass Gasification

Test Goals: The goal of this test was to gasify biomass with hydrogen (hydrogasification) in a bed primed with 3 liters of limestone used as an alkali getter. The expected results were to eliminate the agglomeration problem. The agglomeration problem has been identified by an excess pressure differential across the process filter, causing solid blockage in the reaction zone. An additional goal was to maintain bed temperatures of 760 to 871 °C while hydrogasifying biomass.

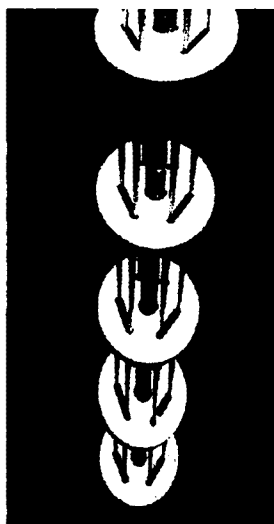


a

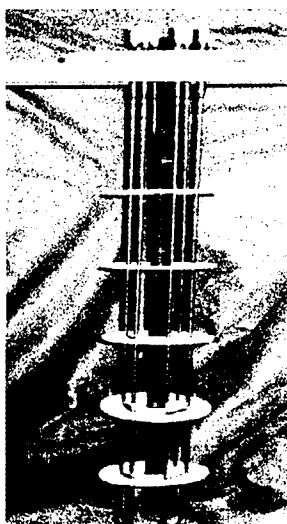


b

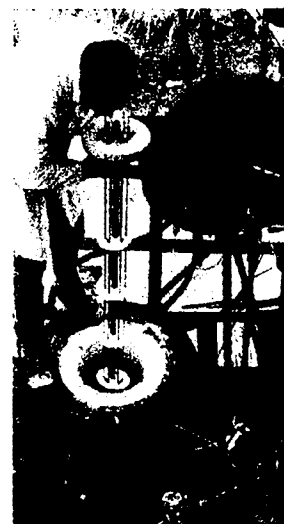
Figure 5-9. The damaged heater elements based on the original design from Arcadis.



a



b



c

Figure 5-10. Installation of new elements and supports.

Results Summary

The agglomeration problem still exists, but there is evidence that it may not be due to hydrogasification. There is a problem with maintaining the 760 to 871 °C bed temperatures, but this may be a result of the possible fluidization problems when the refractory failed in the burner spool piece.

Test Setup and Operation

May 4

12:00 Started burner and electric heater. The electric heater alone could not heat the bed up to 760 °C, so the burner was used in parallel.

May 5

3:00 Operated burner with excess air for 5 hours until TE-814 and TE-809 were >760 °C (Figure 5-11).

8:30 Turned burner off (burner temp TE-020, Figure 5-11) and started adding N₂ to purge air. Purging air is a necessary precaution before adding hydrogen to the reactor.

9:00 Primed the bed with 3 liters of limestone.

9:30 Pressured with nitrogen until a pressure of 30 psi was achieved.

10:20 Started adding hydrogen into the reactor. TE-809 has dropped to ~649 °C.

10:28 Set hydrogen flow to 23 scfm (1.8 kmol/hr); see PDIT-003 in Figure 5-11. Figure 5-12 is a detail from 10:20 to 11:05.

10:35 Turned on feed system after the hydrogen flow stabilized and set biomass flow to 22.7 kg/hr. Notice in Figure 5-12 the steady decline in TE 809.

10:28 Hydrogasified for 30 minutes until TE 809 dropped below 480 °C. Once the temperature dropped below 480 °C, the feed system was turned off. One positive result from this test is there didn't seem to be a increase in pressure differential across the process filter. Figure 5-8 shows the pressure profile. Notice the pressure differential (PD_R101) stayed below 34 kPa during the hydrogasification testing. During air gasification PD_R101 can rise as high as 345 kPa.

11:05 Started adding air (Air_Flow) to burn off the remaining biomass in the reactor. Minutes after adding air an increase in pressure differential

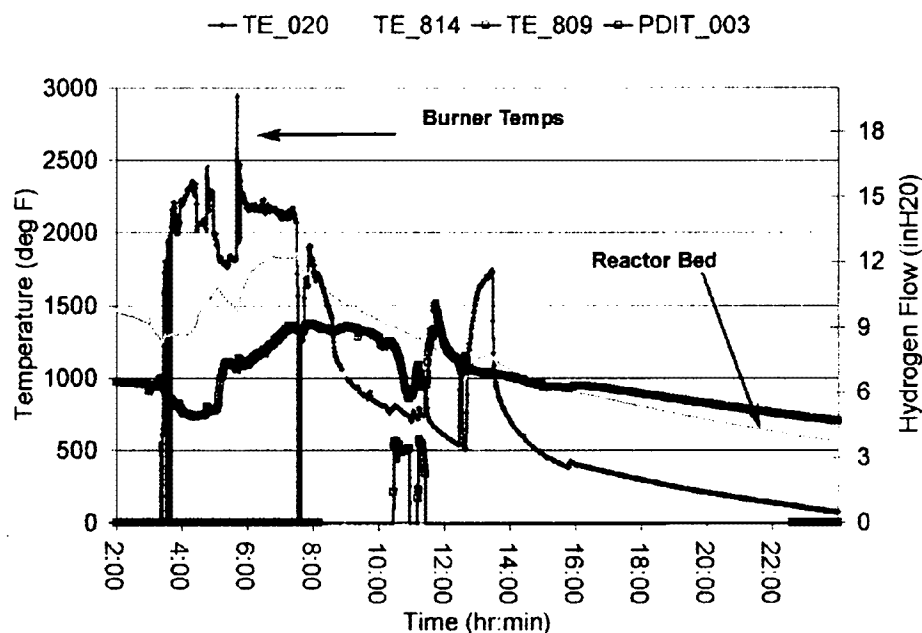


Figure 5-11. Hynol temperature profile before, during, and after the hydrogasification test on May 5, 1999.

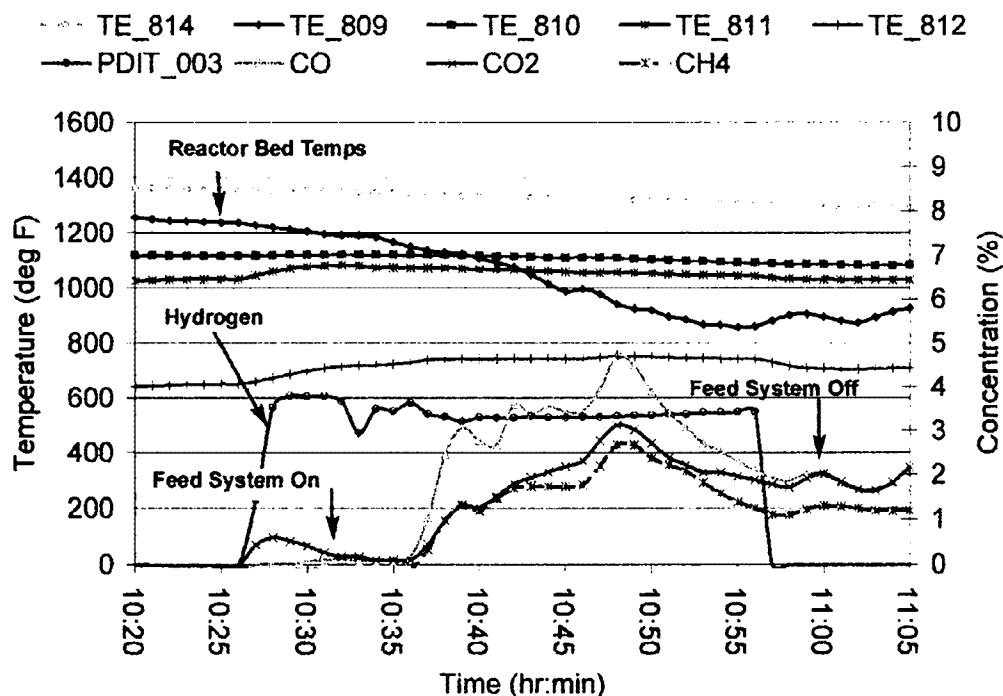


Figure 5-12. Hynol hydrogasification Test for May 5, 1999, reactor temperature profile.

| | |
|--|---|
| <p>across the filter was indicated by a rise in PD_R101 (Figure 5-13). This is believed to be when agglomeration started. More testing is necessary to confirm this theory. The increase in pressure differential could also be explained by the increase in air flow. The pressure rise also may be due to the increased gas flow from air gasification.</p> | <p>13:25 Pulse-cleaned high-pressure filter (small pressure differential change).</p> |
| <p>11:28 Shut off the hydrogen flow (PDIT_003) and increased air flow (Air_Flow) from 11.9 Nm³/hr to 25.5 Nm³/hr to prevent TE-809 from dropping any further (high temperatures are necessary to completely burn off the biomass). Notice in Figure 5-11 the rise in TE-809 with the addition of more air. After about 15 minutes TE-809 starts to drop off, indicating the biomass has been consumed.</p> | <p>13:30 Shut down burner and continued purging the reactor with air and nitrogen.</p> |
| <p>12:45 Turned burner on to cool down reactor slowly and to prevent tar buildup on process filters (recommendation by filter manufacturer). Startup of the burner can be seen by the rise in TE-020 (Figure 5-11) and the increase in the Air_Flow (Figure 5-13).</p> | <p>14:25 Pulse-cleaned high-pressure filter (small pressure differential change).</p> |
| <p>12:50 Pulse-cleaned high-pressure filter (no pressure differential change).</p> | <p>15:05 Pulse-cleaned high-pressure filter (small pressure differential change).</p> |
| | <p>15:45 Shut off air flow and nitrogen.</p> |
| | <p>End of Hydrogasification Test</p> |
| | <p>On May 13, 1999, the burner spool piece was removed to clear some hard blockage material found in the ash removal tube. After removing the burner spool piece, the refractory was discovered to be cracked and damaged. There were many agglomeration pieces on top of the distributor (Figure 5-14). Some pieces looked like damaged refractory and others looked like sand agglomeration. The limestone did not agglomerate, but leftover sand from previous tests could have accounted for the majority of the agglomeration.</p> |
| | <p>A crack developed in the spool lining opposite the burner inlet area near TE-020. The steel shell around the port</p> |

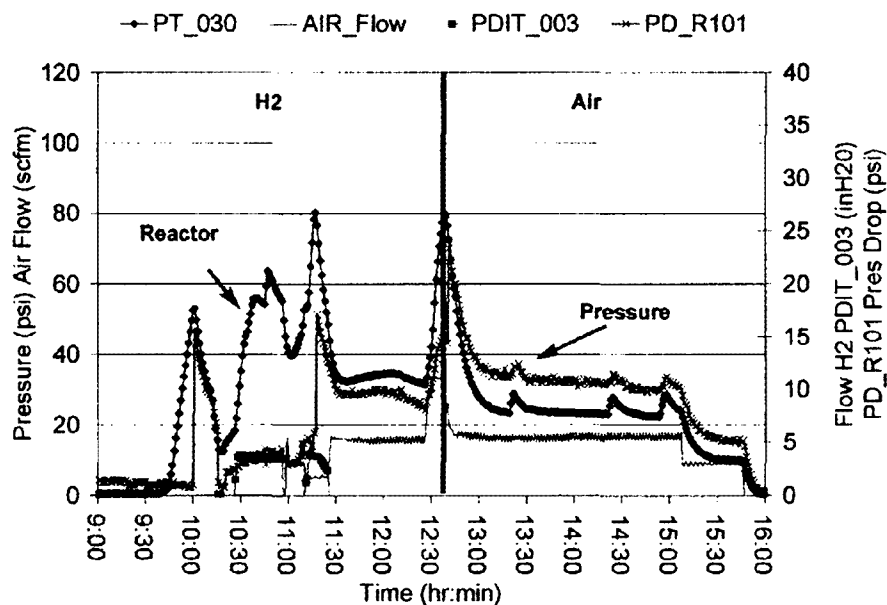


Figure 5-13. Hynol hydrogasification Test for May 5, 1999, reactor pressure and pressure drop profile.

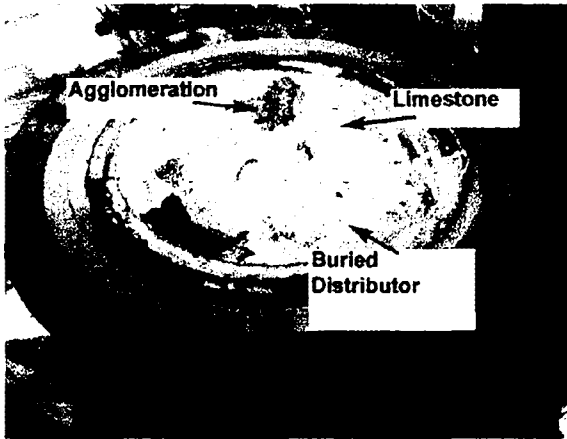
was around 371 °C. After removing the piece, it was noted that the backup insulation was damaged and in some places missing from the top of the spool piece. The inner hot face refractory lining was not badly damaged but did have some minor cracking. The secondary lining (AP Green 19L) melted during operation thus intermediate temperatures must have exceeded 1038 °C (max rating for the 19L).

One of the reasons for the excessive heat damage to the secondary lining is a result of the locations of sensor ports. The sensor ports are holes drilled through the light weight secondary layer and hot face layer. The holes are necessary to measure internal temperatures and pressures. The ports are located in line with the air flow from the heater and from the secondary air. The problem with this location is heat follows the air flow path. The air flow is directly onto TE-020, PT-030 and TE-814. To achieve the 760 °C bed temperatures (TE-809), high gas flows were necessary. The high flow created a large pressure differential around the distributor plate causing a back pressure in the burner. The high back pressure could have allowed the heat flow to find an easier route around the distributor. Since air was directed at two sensor ports, the flow of heat melted the light secondary lining around the sensor. As the refractory melted more air started to flow through the new passage, until the flow made a direct passage around the distributor. Assuming the gas flow made a secondary route around the distributor this would reduce bed fluidization a key factor in gasification. The possible lack of gasification would

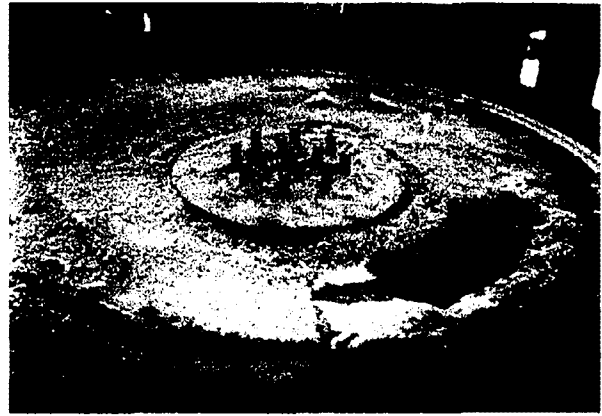
explain the lack of gasification with hydrogen. More tests are necessary once the burner is repaired to confirm hydrogasification bed temperatures problems.

To fix the problem CE-CERT was more conservative with the choice of burner refractory materials. The hot face was changed from Green Clean 60 to Ultra GreenSR. The Ultra GreenSR has better thermal shock resistance and a maximum hot face temperature of 1871 °C. The secondary lining, Greencast19L (max temp 1038 °C) was replaced with Greencast45I. (maximum temperature 1371 °C). These changes increased the safety margin for the insulating material, but it also doubles the heat loss through the burner spool piece. The increased heat loss will still allow the burner to preheat the reactor to operating temperatures as designed. Also, a secondary precaution was incorporated to prevent heat from seeping around sensors by using the same high temperature hot face material around all burner port fittings. This will locally raise the wall temperatures and heat losses, but the areas are small, making the overall heat loss negligible.

In addition to the damaged spool piece, a second crack was noticed on the bottom section of R101 near the feed system (Figure 5-14c). To prevent this crack from propagating, CE-CERT patched the refractory with high-temperature patch materials (maximum temperature of 1371 °C). This repair was completed on-site with out dismantling the vessels.



a



b



c

Figure 5-14. Agglomeration pieces (a) after removal of the bottom burner spool section; (b) refractory damage in the burner spool piece and top view of gas distributor; (c) refractory crack in the main reactor.

The inconel distributor was also damaged during the last gasification test. The center rod deformed under the excessive temperatures and blocked ash from passing through the exit tube. To improve the design, CE-CERT

added extra stiffness to the tubular straight section and introduced secondary air through the Mogas valves (FV-858) to prevent overheating.

6. Discussion

6.1 Hynol Gasification Tests

One of the main problems of operating the Hynol reactor has been sand agglomerations plugging the reactor bed. Table 6-1 lists the elemental analysis from test #1a, #1b, and #3 deposits. The deposits were collected at the entry point of the feed system into the reactor (R101), and the filter ash was sampled at the base of the filter clean out (F104). Also included is an elemental analysis of the biomass ash and sand used for bed material (note that biomass is 1.2 % ash by dry weight). The significant alkali metals are potassium oxide (K_2O) and sodium oxide (Na_2O). From the analysis of the original sand material, a combined 6% of the sand mass is alkali. Another interesting fact is 16.8% of the sand mass was unaccounted for. The analysis of the two deposits is similar to the analysis of the sand.

Alkali problems typically are a result of six months of continuous operation, not a few hours. From simple mass balance calculations it is obvious the agglomeration mass was too large to have come from the biomass. During test #3 only 9.1 kg of biomass was added. This amounts to 100 g of ash, and only 6% of the ash is alkali. The agglomeration in test 3 was about 680 g.

The fact that the agglomeration is similar to the composition of the sand and the fact that the formation occurred within minutes of beginning operation suggest the sand is being fused. The glass making industry uses high alkali sand because the melting point is reduced, thus lowering operating costs. This suggests the agglomerations are a result of the high temperatures in the reactor and use of a sand with a low melting temperature. It could be possible that there are hot spots in the reactor that are not measured by the temperature probes. Additional temperature sensors would be useful in determining whether this is the case.

In test #1 the bed material was sand, but in test #3 the bed material was limestone. Figure 5-14a shows the analyzed agglomeration sitting on a pile of limestone. The explanation for the same deposit analysis in test #1 as in test 3 is that there was some sand in the reactor prior to adding the limestone. The sand was probably left over from test 2. The reactor was cleaned of all sand while the burner spool piece was being repaired.

One solution to prevent fusing the sand in the reactor is to change to a high silica (SiO_2), high alumina (Al_2O_3)

Table 6-1 Elemental analysis for biomass ash, sand, kaolin, and the formed deposits from tests 1a, 1b, and 3.

| Sample ID | Elemental Analysis* | | | | | | | | | | | | |
|----------------|---------------------|-----------|---------|-----------|------|------|---------|--------|--------|----------|------|--------|-------|
| | SiO_2 | Al_2O_3 | TiO_2 | Fe_2O_3 | CaO | MgO | Na_2O | K_2O | SO_3 | P_2O_5 | Cl | CO_2 | Total |
| Fuel Wht Oak | 36.6 | 9.98 | 1.15 | 4.32 | 20.3 | 5.81 | 4.43 | 8.07 | 3.61 | 1.43 | 0.07 | 0.019 | 95.8 |
| Kaolin | 41.5 | 37.8 | 2.17 | 1.02 | 0.03 | 0.06 | 0.21 | 0.17 | 0.06 | 0.18 | 0.02 | 0.02 | 83.2 |
| Sand | 69.9 | 10.1 | 0.38 | 0.67 | 1.56 | 0.09 | 2.31 | 3.48 | 0.12 | 0.05 | 0.01 | 0.03 | 88.7 |
| Deposit 1/99 | 71.3 | 18.3 | 0.77 | 1.35 | 2.67 | 0.29 | 2.73 | 3.61 | 0.07 | 0.18 | 0.01 | 0.14 | 101.4 |
| Deposit 5/99 | 70.0 | 17.7 | 0.73 | 4.88 | 3.02 | 0.29 | 2.36 | 3.64 | 0.08 | 0.15 | 0 | 0.02 | 102.9 |
| Filter 1/99 | 29.2 | 21.0 | 0.87 | 2.06 | 1.63 | 0.82 | 0.46 | 0.87 | 0.41 | 2.4 | 0.06 | 2.98 | 62.8 |
| Filter 5/99 | 38.4 | 24.1 | 1.17 | 4.07 | 1.16 | 0.35 | 0.6 | 0.86 | 0.59 | 1.48 | 0.05 | 0.05 | 72.8 |
| Investo Cast** | 52.1 | 42.2 | 2.09 | 0.35 | 0.02 | 0.02 | 0.10 | 0.10 | n/d | n/d | n/d | n/d | 97.0 |

* Performed by Hazen Research, Inc. using ASTM D2795.

** Investo Cast 50 specification from Lone Minerals MSDS.

and low alkali concentration sand. Investo Cast 50 is an excellent fluidizing bed material (Table 6-1). Investo Cast 50 is made up of 94% silica and alumina. Only 0.2% is from the alkali family. Investo Cast comes in five sizes ranging from 0.2 mm to 1.5 mm. InvestoCast 50 has a mean particle diameter of 0.34 mm, which is small enough to fluidize at the designed gasification velocities (0.3 m/s) and large enough to prevent elutriation (Table 6-2). This new bed material will be used in test 4, planned for December 1999.

Table 6-2. Investo Cast 50 size distribution from Ione Minerals.

| Size (mm) | Weighted % |
|-----------|------------|
| 0.59 | 0.0265 |
| 0.42 | 0.1638 |
| 0.3 | 0.1065 |
| 0.22 | 0.0385 |
| 0.15 | 0.0053 |
| Mean | 0.3406 mm |

* Investo Cast 50 specification from Ione Minerals MSDS.

Although InvestoCast 50 would add to the gasification operating cost, it is expected that fluidization can be maintained without the sand bed material. CE-CERT is using the bed material to help start the gasification process. Once gasification has been achieved, the ash

and char would become the fluidized media. Tests will be performed to show that this theory is correct.

The analysis on the white oak biomass agrees with other analyses. Table 6-3 lists several biomass Ultimate analyses. Notice the carbon, oxygen, and hydrogen percentages all agree within a few percent. The low ash content of the white oak fuel is an advantage for our process. The white oak fuel should perform well once operation is successful. The ash elemental analysis of the biomass is also similar to other fuel types (Table 6-4).

The hydrogasification test did show signs of hydrogasification during the 20-minute test before bed temperatures started to drop below 482 °C (Figure 5-12). Based on the peak value of effluent concentration, the carbon conversion efficiency can be estimated (Table 6-5). The calculation requires a knowledge of the total mass flow at the effluent. Unfortunately, the effluent flow is based on volume, not mass. Volumetric flows depend on gas density, which is a function of composition. In addition, the condensate trap before the flow meter was not operating correctly, so water condensate was flowing through the flow meter. This would affect the overall effluent flow result. Taking all these errors into consideration, it is possible to bound the mass flow in the effluent and calculate the carbon conversion efficiency.

Table 6-3. Fuel ultimate analysis comparison*.

| Sample ID | Dry basis | | | | | | |
|---------------|-----------|--------|----------|--------|----------|--------|------|
| | Water | Carbon | Hydrogen | Oxygen | Nitrogen | Sulfur | Ash |
| Fuel Wht Oak | 7.2 | 49.7 | 5.46 | 43.32 | 0.37 | 0.03 | 1.12 |
| Furniture Wst | 12 | 49.87 | 5.91 | 40.29 | 0.29 | 0.03 | 3.61 |
| Urban Wood | 37 | 51.44 | 5.67 | 38.013 | 0.41 | 0.03 | 4.32 |
| Alder Fir | 52 | 51.02 | 5.8 | 38.54 | 0.46 | 0.05 | 4.13 |

* White Oak is reported by Hazen Labs following ASTM D3172 the other fuels are from Miles et al. (1998) alkali deposit survey.

Table 6-4. Fuel ash elemental analysis comparison.

| Sample ID | Ash Elemental Analysis | | | | | | | | | | | | | |
|---------------|------------------------|--------------------------------|------------------|--------------------------------|-------|------|-------------------|------------------|-----------------|-------------------------------|------|-----------------|-------|-------|
| | SiO ₂ | Al ₂ O ₃ | TiO ₂ | Fe ₂ O ₃ | CaO | MgO | Na ₂ O | K ₂ O | SO ₃ | P ₂ O ₅ | Cl | CO ₂ | Total | Other |
| Fuel Wht Oak | 36.64 | 9.98 | 1.15 | 4.32 | 20.3 | 5.81 | 4.43 | 8.07 | 3.61 | 1.43 | 0.07 | 0.019 | 95.8 | 4.2 |
| Furniture Wst | 57.62 | 12.23 | 0.5 | 5.63 | 13.89 | 3.28 | 2.36 | 3.77 | 1 | 0.5 | n/a | 0 | 100.8 | -0.8 |
| Urban Wood | 39.96 | 12.03 | 0.87 | 7.43 | 19.23 | 4.3 | 1.53 | 5.36 | 1.74 | 1.5 | n/a | 6.05 | 100.0 | 0.0 |
| Alder Fir | 35.36 | 11.54 | 0.92 | 7.62 | 24.9 | 3.81 | 1.17 | 5.75 | 0.78 | 1.9 | n/a | 1.85 | 95.6 | 4.4 |

* White Oak is reported by Hazen Labs following ASTM D3172 the other fuels are from Miles et al. (1998) alkali deposit survey.

Table 6-5. Test data for May 5, 1999, hydrogasification test.

| | CO (%) | CO ₂ (%) | CH ₄ (%) | H ₂ Flow (scfm) | Effluent Flow* High (scfm) | Effluent Flow* Low (scfm) |
|---------|--------|---------------------|---------------------|----------------------------|----------------------------|---------------------------|
| Average | 3.36 | 2.10 | 1.83 | 23.15 | 36.84 | 11.05 |
| Max | 4.74 | 3.12 | 2.67 | 24.74 | 45.14 | 13.54 |
| Min | 2.45 | 0.97 | 0.96 | 19.47 | 21.74 | 6.52 |
| Stdev | 0.65 | 0.61 | 0.48 | 00.95 | 05.33 | 1.60 |

*Effluent flow is unknown because process gas molecular weight ranges from high to low, but the bounds are known and listed as High and Low. (High assumes effluent is mostly hydrogen and very little water and Low assumes mostly nitrogen and water with a small amount of hydrogen.)

Table 6-6. Composition data from hydrogasification test conducted by EPA using designed input flows and the test conducted at the Hynol facility located at UC Riverside.

| Component | Input Flow* (kmol/hr) | Product* (mole %) | Input Flow** (kmol/hr) | Product** (mole %) |
|------------------|-----------------------|-------------------|------------------------|--------------------|
| Biomass | 22.7kg/hr | 0 | 22.7kg/hr | 0 |
| CO | 0.161 | 11.05 | 0 | 4.7 |
| CO ₂ | 0.098 | 05.86 | 0 | 3.1 |
| CH ₄ | 0.044 | 17.87 | 0 | 2.8 |
| H ₂ O | 0.285 | 19.69 | 0 | Not measured |
| H ₂ | 1.771 | 40.08 | 1.8 | Not measured |
| N ₂ | 0.171 | 05.31 | 0 | Not measured |
| Effluent | N/A | 40.3 scfm | N/A | 45/14 scfm |

*Values from laboratory and theoretical analysis by EPA and Arcadis (30 atm).

**Preliminary test conducted at UC Riverside Hynol Facility (2 atm).

The range of expected effluent flows is indicated in Table 6-6.

Because the input flow is only hydrogen, the majority of the gas minus that identified by the NDIR analyzers should be hydrogen. Assuming all the unknown gas is hydrogen, a carbon conversion efficiency of 33% is the result. If there was more nitrogen than hydrogen (highly unlikely), the carbon conversion efficiency would only be 13%. In either case only the process conversion efficiency is lower than the expected 87%. One reason for the poor conversion is a result of low gasification temperatures. Dong and Cole (1996) recommend temperatures >800 °C, but CE-CERT operated at 600 °C. Future tests will be performed after the bed reaches 800 °C. CE-CERT also recommends replacing the effluent volumetric flow sensor with a true mass flow meter.

A thermal evaluation of the refractory material in R101 was performed based on the results of test 3. The

evaluation was necessary to understand whether there were any unexpected heat losses during operation (Figure 6-1).

An unexpected heat loss would be evident by large temperature drops from one sensor to the next. The measure used is temperature per length between sensors. There are three physical sections to the reactor (Figure 6-2). The refractory is only insulated on the inside of the structural piping. External insulation was not possible due to temperature limitations of 204 °C on the steel surface. It is expected that section 1 should have a highest value, section 2 should be low and section 3 should be medium. Section 1 should be much higher than sections 2 and 3 because of its high-density refractory.

Figure 6-2 identifies the seven locations of temperature sensors within the three sections. The heat loss between locations 2 and 3 is 3.4 times the heat loss between locations 3 and 4. The low 0.26 °C/in. (0.01 °C/mm) heat

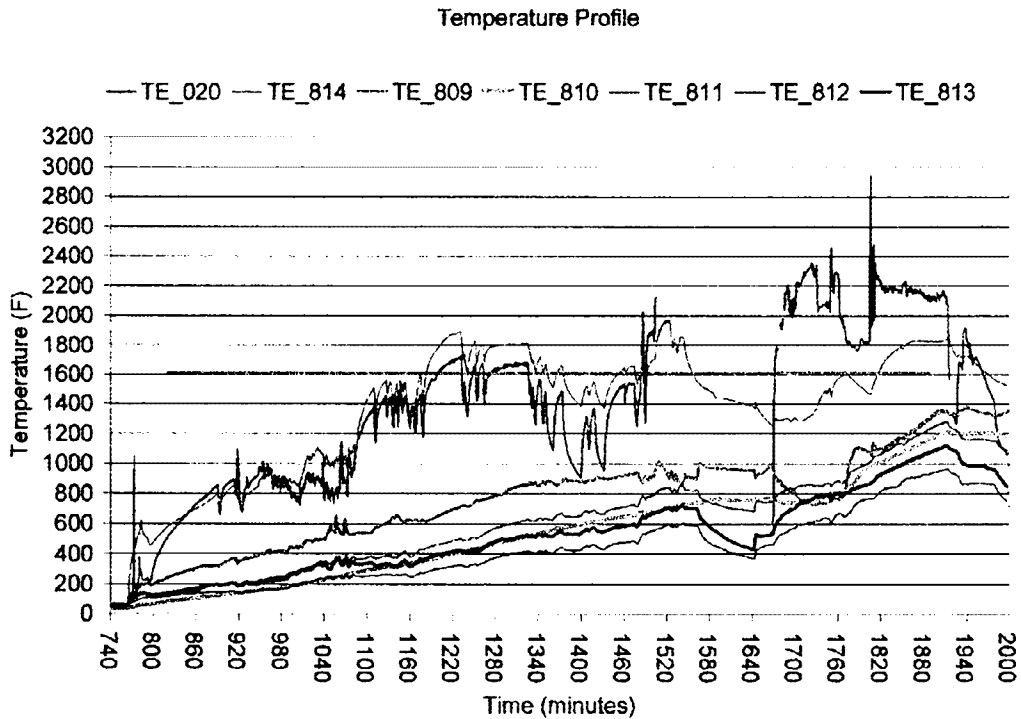


Figure 6-1. Temperature profile for test 3, from start up to shut down of the Hynol reactor.

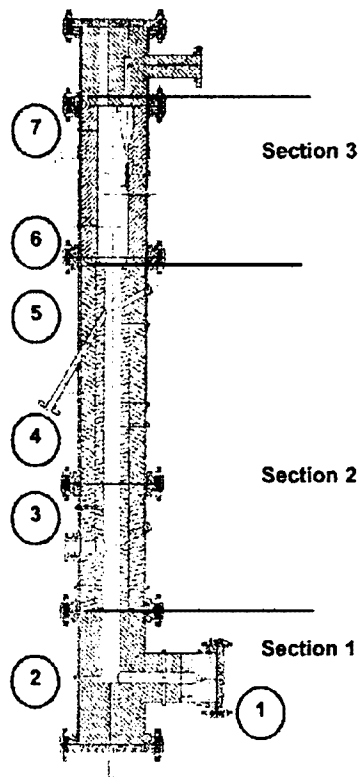


Figure 6-2. Reactor section 1 is the burner; section 2 is the main gasification reaction zone; and section 3 is the reduced velocity free board zone. The circled numbers are temperature sensor locations.

loss in locations 5 and 6 (Table 6-7) is a result of not inserting the temperature sensor into the gas stream. Overall, the heat into the reactor equates with the heat loss by the reactor and flowing gases. Approximately 43kW of heat (burner + electric heater) was going in and an accounted 40 kW was going into heating the reactor gas volume, refractory losses, and the burner gases.

Table 6-7. Heat loss as a function of length based on test 3 with the Hynol reactor.

| Section | Length | Temp/Length |
|---------|--------|-------------|
| # | In | °C/in |
| 6-7 | 34 | 1.97 |
| 5-6 | 35 | 0.259 |
| 4-5 | 28 | 1.57 |
| 3-4 | 37 | 1.61 |
| 2-3 | 58 | 5.51 |
| 1-2 | 12 | 18.1 |

6.2 Facility Design and Construction

The major difficulties confronting this project were a result of the Hynol pilot-scale facility design. Improved design and improved peer-review of the design could have prevented many flaws that caused significant setbacks and delays later. Additionally, CE-CERT should have insisted on demonstration of successful operation before accepting certain components and subsystems.

There have been many successes in this project. The feed system has been made to operate automatically without bridging or overheating. The modified electric heater has operated without too much attention, and the burner is able to preheat the reactor area up to operating temperatures as needed.

6.3 Data Quality

Since steady state hydrogasification was not achieved, overall material balance cannot be used as a general quality indicator of the test data. The quality indicator in this study relies on the precision of each of the individual measurements involved in the testing.

The measurements in the Hynol reactor tests include system pressure, reaction temperature, the flow rates of

hydrogen, methane, air, and nitrogen, the biomass feed rate, and the composition of the biomass samples. All of these measurements were conducted in accordance with the data quality goals listed in the sample plan and QA plan (Appendix IV).

The ASTM standard methods were used for composition analysis of the biomass, fluidized bed material, char, and deposit formations from the Hynol facility. Multiple samples were analyzed. The results of the analysis met the data quality indicators listed in the QA plan.

Each of the orifice plate flow systems was calibrated with a DGM before and after testing. The performance of the orifice plate was stable over time and met the quality indicators of the QA plan.

The desired system pressure was maintained with a back-pressure regulator. The system pressure variation exceeded the target of the QA plan, due to the inability to reach steady state gasification and a flow capacity problem with the back pressure regulator. The flow capacity problem has been resolved. Future tests should meet the system pressure target of the QA plan assuming steady state gasification is achieved.

A graduated glass tube was installed for the steam flow metering. Unfortunately, due to unstable gasification, steam addition was not performed and therefore no indication of the quality of the data was recorded or measured.

Type K thermocouples were used to measure heater, burner, and reaction zone gas temperatures. All thermocouples were calibrated before installation into the reactor following ASTM methods listed in the sample plan. All reaction zone temperature probes were installed into the process by 25.4 mm. All other TCs were installed ~10 mm into the process. Depths of all TCs were confirmed during vessel assembly and repair by visual inspection.

The desired quality indicators for the Hynol facility are from steady state operation. Because steady state operation was not achieved, meaningful carbon conversions efficiency and mass balances were not determined and further testing is needed to evaluate hydrogasification of biomass materials.

7. Conclusions and Recommendations

7.1 Conclusions

1. Biomass feeding is automated and delivers 22.7 kg/hr to the high-pressure hydrogasification reactor at 10 atm and has been operated without material automatically at 30 atm.
2. Electric heater support version 3 is reliable and capable of preheating ambient inlet gases to 649 °C. Design version 3 uses silicon carbide as the support rod for 5 ceramic disk supports.
3. The reactor is capable of withstanding 5.2 MPa with a leak rate less than 10% over 24 hours.
4. The flow measuring orifice plates are calibrated to within $\pm 2\%$ of the actual flow conditions for each gas. Calibrations were completed at operating pressures using nitrogen and a calibrated dry gas meter. Because hydrogen is such a light gas its calibration was done at operating pressures using hydrogen gas and a dry gas meter.
5. During operation designed skin temperatures are below the maximum rated skin temperature of the pressure vessels.
6. Manual and automatic control of all valves and motors is possible using OPTO 22 software and hardware.
7. Data logging is successful using the OPTO 22 process control software and hardware package.
8. Burner spark system is reliable and has survived more than 100 hours of service. The final igniter design is a modified automotive spark plug as shown in Figure 4-2.
9. The burner is controlled by monitoring a thermocouple located in the flame area.
10. Sample system temperatures are below that necessary to capture high temperature alkali gases and tars. These compounds will be analyzed from the sample tube. Future designs should allow proper sampling to collect for alkali and tar formations.
11. Sample conditioning is accomplished through a series of high-pressure, high-temperature impingers. Successful operation of the sample system has been demonstrated.
12. Analyzer delay times from the reactor sampling to the analyzer are dependent on the sample pressure, sample length, and analyzer response. The delay due to pressure is the most significant. At 10 atm, the delay time from sample probe to sample path is about 10 minutes. The delay from the sample path to the analyzer is 15 seconds. The analyzer response time is about 0.5 seconds. The overall sampling delay is 10 minutes at 10 atm.
13. Air gasification has been performed with success, but have not been optimized.
14. Final refractory materials for B-037 are a two piece lining with a hot face Ultra GreenSR and a secondary lining using GreenCast 47. These materials are designed for maximum peak temperatures of 1871 °C and maximum operating temperatures of 1427 °C.
15. Agglomerations occurred due to high alkali concentrations in the fluidized bed material with bed temperatures of 700 °C or greater. Care needs to be used when selecting fluidized reactor bed materials.

-
16. Ash removal cycles are successful at ambient and high temperature. Agglomeration formation will block the ash removal passage.
 17. Bed temperatures of 800 °C were easy to obtain with air gasification.
 18. Bed expansion and pressure drop across the bed were indicated, but not optimized for gasification.
 19. Optimum carbon conversion efficiency has not been realizable due to agglomeration problems during gasification and low bed temperature.

20. No efficiency data are available for the internal cyclone.

7.2 Recommendations

The hydrogasification reactor has the potential to be a viable way to convert biomass into a liquid fuel. The high carbon conversion efficiency with hydrogasification shows the Hynol process could be an economical and low-CO₂ producing method for methanol production. Future testing can succeed if problems with agglomeration and the feed system are solved. Table 7-1 presents recommended test parameters for future tests. Also the process should be analyzed for the actual exit gas quality to predict other design problems for phase 2 and 3 of the methanol production process.

Table 7-1. Test conditions to be used for CE-CERT Hynol test facility.

| | Hynol UC Riverside Test 4 Nov 10, 1999 Expected / Operational | Hynol Arcadis/EPA Simulations |
|--|---|-------------------------------------|
| Temperature | 800°C (1472°F) | 800°C (1472°F) * |
| Pressure | 8 atm (103 psig) | 30 atm (442 psia) * |
| Solids Fast Residence Time (average) | n/a | 15 sec * |
| Solids Slow Residence Time (average) | n/a | 7.86 hr * |
| Gas Residence Time | 9 sec ** | 8 sec |
| Superficial Velocity | 0.27 m/s ** | n/a |
| Gaseous Input Flow Rate | 1.26 kmol/hr (4.2kg/hr)** | 2.53 kmol/hr ** |
| H2 | 95% ** | 69.9 %** |
| CH4 | 0% ** | 1.80 %** |
| CO | 0% ** | 8.95 %** |
| CO2 | 0% ** | 3.90 %** |
| H2O | 0% ** | 0.0 %** |
| N2 | 5% ** | 7.0 %** |
| Biomass Input Flow Rate | 18.5 kg/hr (41 lb/hr) **** | 22.7 kg/hr (50 lb/hr) *** |
| C | 49.7 %wt | 51.5 %wt * |
| H | 5.5 %wt | 6.20 %wt * |
| O | 43.3 %wt | 41.4 %wt * |
| N | 0.4 %wt | 0.42 %wt * |
| H2O | 18.7 %wt | 10.0 %wt * |
| Ash | 1.12 %wt | 0.47 %wt * |
| Ash Exit Flow Rate | 1.14 kg/hr | 1.4 kg/hr * |
| Sand Exit Flow Rate | 0.3 L/hr | 0.3 kg/hr * |
| Kaolinite Exit Flow Rate | n/a | 0.2 L/hr * |
| H/C biomass Ratio (by mass) | 0.432 | 0.459 |
| Hydrogasification Products | 1.99 kmol/hr (21kg/hr) ** | 3.056 kmol/hr (45 kg/hr)** |
| CH4 | 10.5% ** | 19.1% ** |
| CO2 | 2.76% ** | 6.3 % ** |
| CO | 14.0% ** | 12.1% ** |
| H2 | 85.8% ** | 37.1% ** |
| N2 | 3.27% ** | 5.9 % ** |
| H2O | 10.6% ** | 18.0% ** |
| Temperature Profile/Distribution | Reaction Dependent | Electric Heater Control |
| TE-809b | 800 | 800 * |
| TE-809 | 770 | 800 * |
| TE-810 | 730 | 800 * |
| TE-811 | 700 | 800 * |
| Pressure Differential Expected (Distrib only) | ~15 inH2O | n/a |
| Pressure Differential Expected (w/out Distrib) | ~15 inH2O | n/a |
| Bed Material | InvestoCast 50 | Sand * |
| Particle Diameter | 0.34 mm (0.013in) | n/a |
| Volume Added | 15 L | n/a |
| Composition | 52% SiO2, 42%Al2O3 | n/a |
| Static Bed Height @ Start-up | 45.3 cm (18 in) | n/a |

* Evaluation of Biomass Reactivity in Hydrogasification for the Hynol Process by Yuanji Dong and Edward Cole, EPA-600/R-96-071

** Calculated with Stanjen at operating pressure and temperature using the above inputs to the reactor (Constant T and P).

*** Hynol Process Evaluation by Borgwardt EPA-600/R-97-153

**** Laboratory Analysis of White Oak Biomass Hazen Labs dry basis except for 11.35 kg/hr biomass and 18.7% moisture.

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Appendix I Environmental Impact Report

University of California, Riverside

Methanol Production Facility
UCR Project No. 958985-1
University of California, Riverside

July 1996

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This statement is prepared in
compliance with the California
Environmental Quality Act

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INTRODUCTION AND SUMMARY

This initial study has been prepared to evaluate the potential environmental impacts of a proposal by the University of California, Riverside to establish a prototype facility for generation of methanol from wood chips at an off-campus location within an established industrial park in the City of Riverside. This study has been completed in conformance with the California Environmental Quality Act and the University's procedural handbook for implementation of CEQA.

Project Title

Methanol Production Facility, UCR Project Number 958985-1

Project Location

The proposed project is located on the site of the Bourns, Incorporated manufacturing plant, at 1200 Columbia Avenue, near the intersection of Columbia and Iowa Avenues in the City of Riverside (Figures 1 and 2). The site is approximately 1.5 miles northwest of the main campus.

Project Site and Environmental Setting

The project site is part of an approximately 25 acre site occupied by manufacturing facilities of Bourns, Incorporated, which is, in turn, located within the approximately 1,200 acre Hunter Business Park industrial area in the northeast quadrant of the City of Riverside. The Bourns site is developed with an electronics manufacturing facility. The proposed site for the methanol production test facility consists of unused lands along the east boundary of the Bourns site. Figure 3 presents a recent aerial photograph of the Bourns plant site and the proposed methanol production facility location.

As the founding benefactor of the UCR College of Engineering, Bourns provides space at its Riverside plant to house the College's Center for Environmental Research and Technology (CE-CERT). The college presently occupies about 36,000 square feet of office and research space which houses about 75 scientists and students conducting various research efforts related to air pollution and renewable energy.

The Bourns plant consists of a total building area of approximately 200,000 square feet and houses facilities for the manufacture of electronic circuit components. Operations are primarily conducted indoors; however, there are outdoor storage and receiving areas adjacent to the proposed site for the methanol production facility.

Rail lines operated by the Atchison Topeka and Santa Fe company are located on a slightly elevated alignment along the east boundary of the project site.

Project Description

Due to the technical nature of the physical and operational aspects of the proposed facility, the project description is presented in several sections to provide the reader an understanding of : 1) the overall project purpose, 2) the nature of the process product, 3) the mechanical aspects of the process, 4) relevant details of facility operation, 5) the proposed physical improvements, and 6) the regulatory aspects of project establishment and operation.

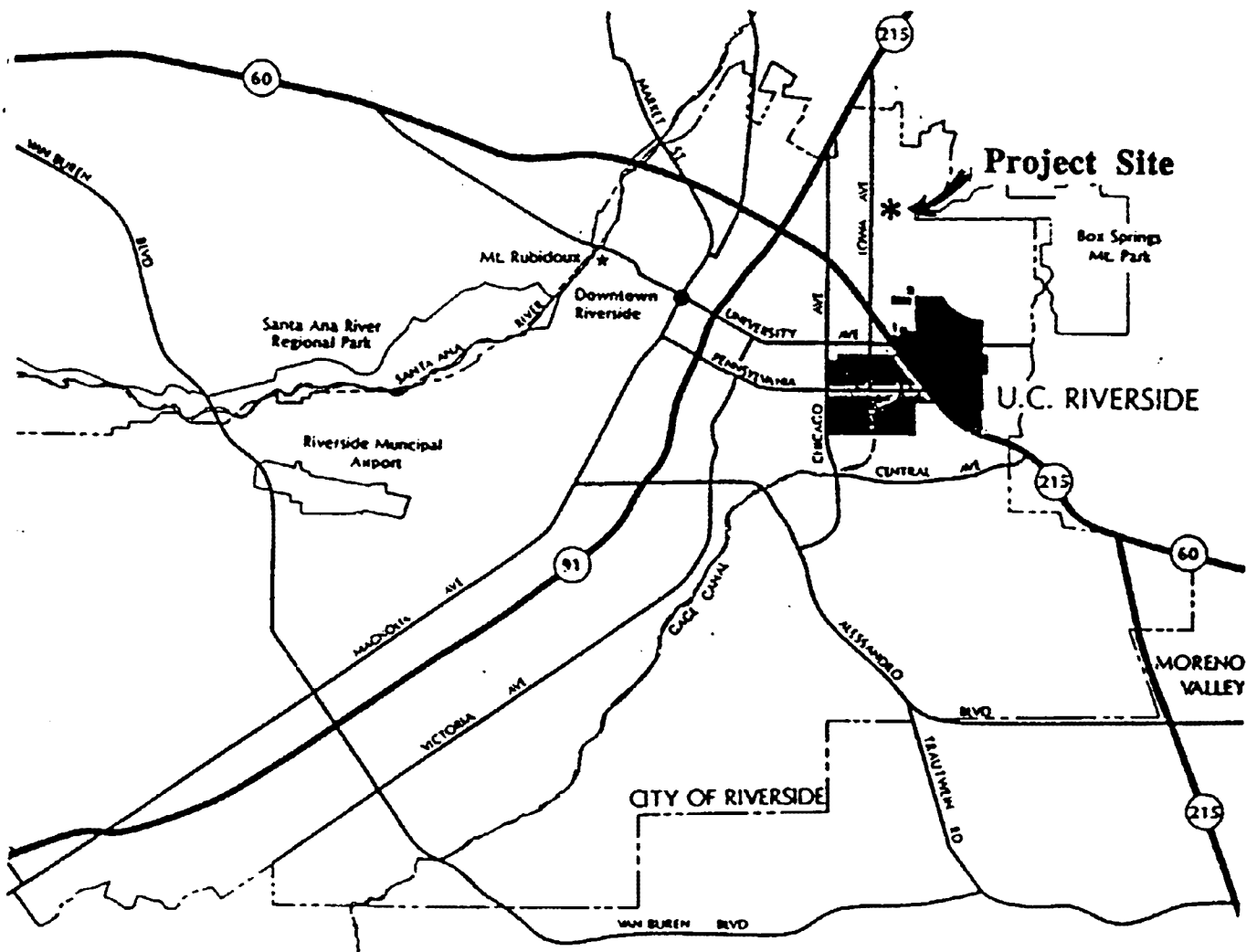


Figure 1
Regional Location

Initial Study for
University of California Riverside
Methanol Production Facility

W.O. 96-05
June 1996

ALBERT A
WEBB
ASSOCIATES
ENGINEERING CONSULTANTS





Source: Riverside, CA, 1995

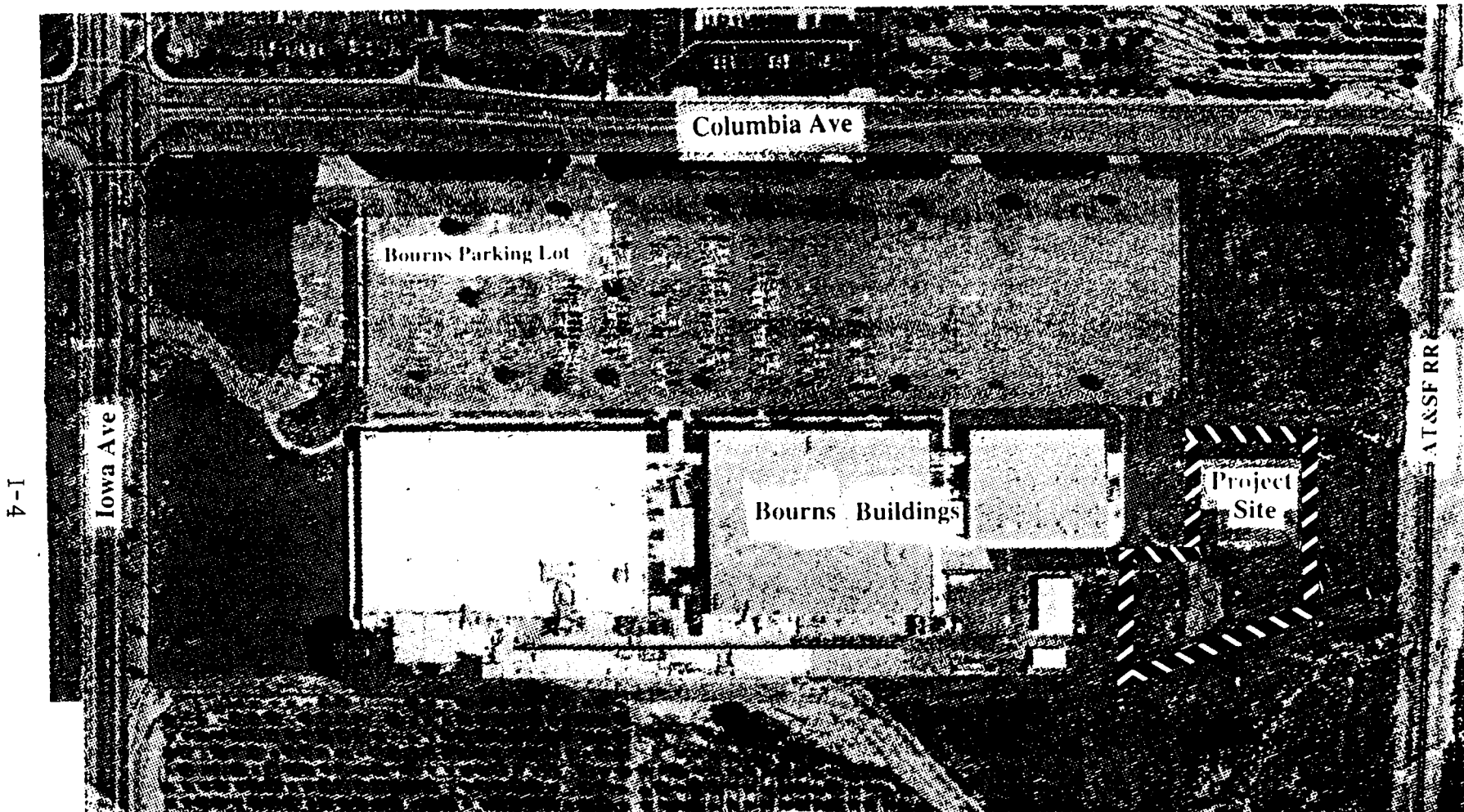
W.O. 96-05
June 1996

A L B E R T A
WEBB
A S S O C I A T E S
E N G I N E E R I N G C O N S U L T A N T S



Figure 2
Project Setting

Initial Study for
University of California Riverside
Methanol Production Facility



W.O. 96-05
June 1996

ALBERT A
WEBB
ASSOCIATES
ENGINEERING CONSULTANTS

Figure 3
Bourns Plant & Project Site

Initial Study for
University of California Riverside
Methanol Production Facility

Project Purpose and Objectives

The proposed project will construct a small-scale plant ("bench scale") to demonstrate the feasibility of an advanced technology for production of liquid methanol from biomass. The primary goal of this project is development of a process that will provide a less-polluting alternative to petroleum-based fuels to reduce greenhouse gas emissions from mobile sources. This demonstration project is in support of national security goals to develop fuel sources derived from indigenous resources, as well as federal, state and local goals to develop cleaner-burning fuels for motor vehicle use.

Methanol as a Fuel

Methanol is a colorless, tasteless liquid with a very faint odor. Methanol is favored as an alternative to gasoline or diesel fuel for passenger cars, light trucks, heavy duty trucks and busses because it produces reduced emissions of reactive hydrocarbons, particulates and nitrogen dioxide. Methanol is less flammable than gasoline and burns more slowly and with less heat. Due to its outstanding performance and fire safety characteristics, methanol is the fuel of choice for Indianapolis-style race cars.

Methanol Production Process

Overview. The central component of the proposed methanol production facility is a series of three reactors called the hydrolysis reactor (HPR), steam pyrolysis reactor (SPR) and methanol synthesis reactor (MSR). Wood chips are fed into the HPR in the presence of natural gas and hydrogen under high pressure (440 pounds per square inch) and high temperature (1450 degrees Fahrenheit) to produce methane. Methane drawn from the HPR is fed into the SPR, where steam is added, and under conditions of high pressure (440 pounds per square inch) and high temperature (1600 degrees Fahrenheit), hydrogen and carbon monoxide are produced. The hydrogen and carbon monoxide are cooled and then reheated in the MSR (500 degrees Fahrenheit, 440 to 600 pounds per square inch) in the presence of a catalyst to produce methanol. Hydrogen and methane gas, which are by-products of the methanol synthesis process, are recycled to the HPR. Heat recovered from SPR product gases and heat generated by the MSR process provide process heat for biomass drying and steam production. A feed of compressed air, natural gas, hydrogen, and nitrogen is used during start-up.

Phasing. Initial improvements will involve only the hydrolysis portion of the reactor system. During this initial phase, process gases from the second (SPR) and third (MSR) stages of the integrated process must be synthesized. This synthesis will be effected from gases stored in mobile tanks and standard laboratory bottles. During HPR-only operation, no methanol will be produced and all product gases will be burned in a flare. The results of the HPR-only phase are intended to determine optimum operating conditions and to identify any necessary modifications to the design or operation of the integrated system. The HPR-only system will be tested over an approximately eight month period, following an approximately four month construction period. A second research phase will add the SPR unit. During operation of the HPR-SPR configuration, no methanol is produced and process gasses will continue to be burned in a flare. A final phase involving the integrated HPR-SPR-MSR system will then be tested. The timing and duration of the HPR-SPR and integrated system test phases will be dependent upon results of each prior test phase; however, all work will be completed within the three and one-half year estimated project life. The test facility will be dismantled and removed following the demonstration project, in compliance with the lease agreement between the College of Engineering and Bourns.

Raw Materials. One of the primary raw materials is wood chips. Sand and kaolinite, a silica clay, are also fed into the HPR with the wood chips. Sand helps maintain heat and accelerates the reaction by abrading the wood chips, and kaolinite absorbs alkali metals to eliminate formation of

sand balls that could plug the system. The mixed solids will be fed by hand into a staged vessel called a lockhopper, which uses compressed nitrogen gas to progressively raise the pressure of the biomass to that of the HPR reactor vessel.

Pressurized gases are required for both the initial HPR-only configuration and the integrated system. Nitrogen is used to pressurize the mixed solids feed, to operate the emergency shut-off valves, and to fill the reactor vessels when not in use. Hydrogen, natural gas, carbon monoxide, carbon dioxide and nitrogen will be mixed in HPR-only tests to simulate the recycled process gases in an integrated system. Once the integrated system is completed only natural gas and nitrogen will be required.

Waste Products. The waste stream from the process includes ash from the HPR reactor, vent gases resulting from reactor shutdown, and purged materials from emissions control filter media. Considering the nature of the raw materials, solid waste generated by the methanol production process is not expected to require special handling. In accordance with established campus programs, waste will be tested to determine the need for special handling. If special handling is required, it can be incorporated into the existing campus materials management program.

Facility Operation

As a demonstration facility, the plant will operate in a series of tests, typically involving a five-day, 24-hour per day period once each month.

Researchers for this demonstration project are currently employees at CE-CERT and Acurex Environmental Corporation. A limited number of additional temporary laborers will be hired during the periodic test runs to assist with manual tasks related to raw material loading and waste removal.

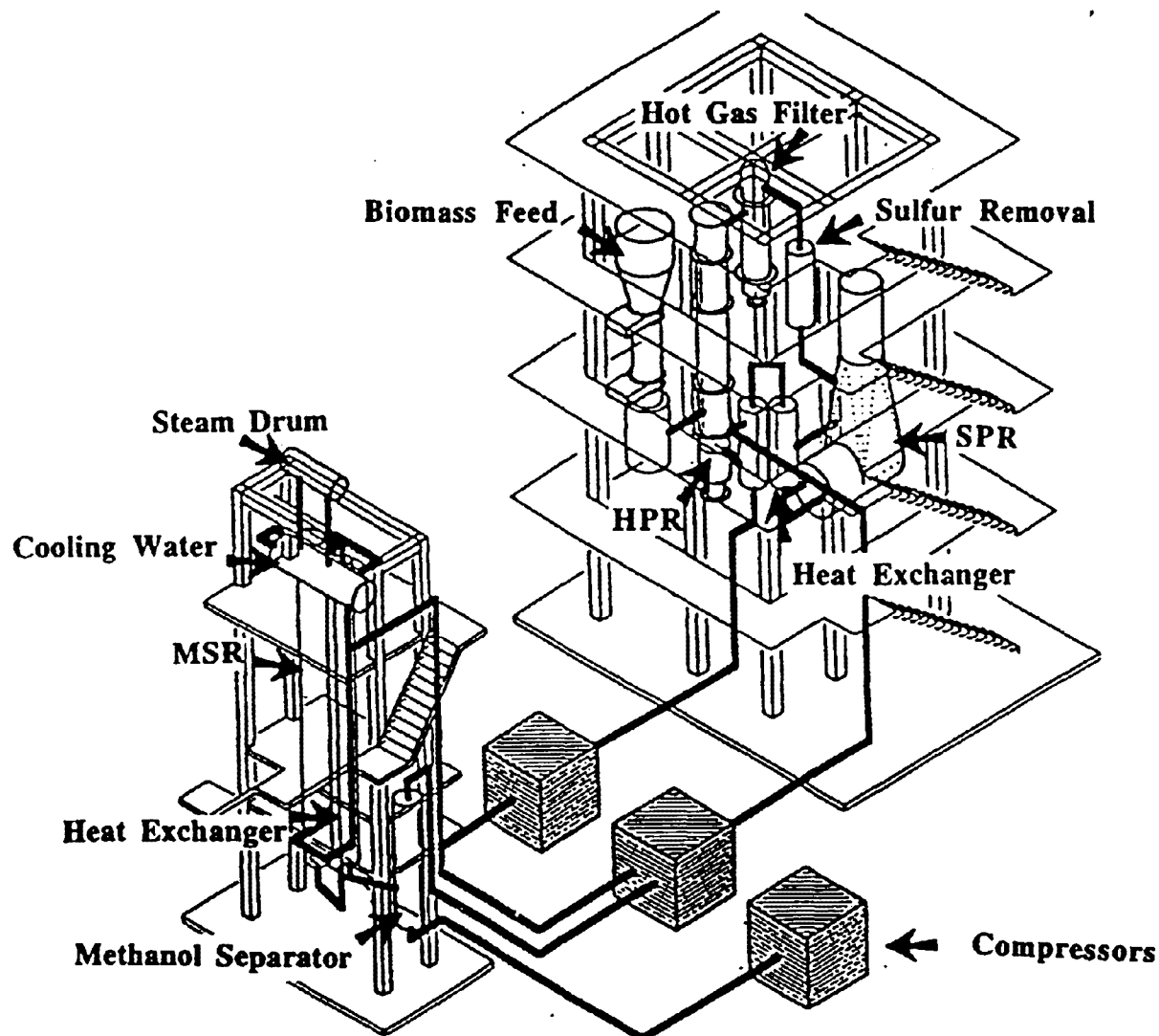
Deliveries and removals are expected to involve 40 or fewer trips per month and will largely be spread over a three week time-frame corresponding to the week before a run, the week of a run, and the week after a run.

Proposed Improvements

The proposed plant layout is illustrated in Figure 4 and a conceptual design for the reactor structure is presented as Figure 5.

The following describes relevant components of the plant physical design:

- **Reactor Structure** - The biomass feed, HPR, and SPR components are all contained within an open, metal frame structure with approximate dimensions of 20 feet by 20 feet and a height of about 30 feet. An external stairway and walkways provide access to various controls associated with the mechanical components. The MSR unit is contained in a separate structure of similar design.
- **Flare Stack** - All vent gases from the reactor vessels are directed to a flare. The flare will be located within the fenced facility site. The flare will consist of a low-profile control box housing a pilot light supply valve and a multiple-pipe assembly consisting of three small-diameter (1/2 to 8 inches) standpipes and a top-mounted enclosure that contains the flame. The entire assembly is approximately 12 feet in height.



The Hynol facility with the methanol synthesis unit in the foreground, compressors in the middle, and the HPR/SPR/feed system in the background

Source: "Hynol Process Engineering - Process Configuration, Site Plan, and Equipment Design"
Acurex Environmental Corporation, April 27, 1995

W.O. 96-05
June 1996

A L B E R T A
WEBB
A S S O C I A T E S
E N G I N E E R I N G C O N S U L T A N T S

Figure 5
Reactor System Typical Design

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- **Emissions Control** - The exhaust stream from the HPR vessel is passed through a barrier filter to capture particulates, which could include carbon particles (wood waste) and sand, and through a second adsorber filter for sulfur removal. These filtering processes are essential to the proper operation of subsequent reactor processes. The vent of the biomass feed unit also includes a filter to capture particulate emissions.
- **Insulation** - Insulating layers on pipes and reactor vessels reduce surface temperatures; however, exterior wall temperatures may range up to 150 degrees Fahrenheit.
- **Gas Storage** - Hydrogen, nitrogen and carbon monoxide will be stored in pressurized tanks (approximately 5,500 gallons, water capacity). These larger tanks will only be required during the initial, approximately 8 month HPR-only phase. Additional nitrogen will be stored in smaller pressurized bottles (14 inches long by 6 inches in diameter, about 50 total).

The large tanks of hydrogen, nitrogen and carbon monoxide will be mobile and will only be located on the site during the approximately 5-day duration of each test run. The gas supplier will deliver the tanks prior to each run and remove them after each run. Recharging of the tanks is expected to be required once during each test.

- **Compressors** - Three compressors will be utilized in the HPR-only system - one to compress carbon dioxide gas, one to compress natural gas, and the other to compress air. In the integrated system, a small blower and a process gas compressor are also required for the SPR.
- **Safety Features** - Facility operation presents two categories of potential safety hazards:

Fire and Explosion: The nature of compressed gases and wood chips which are raw materials, the production process which utilizes high temperature and pressure, and the nature of the methanol product, all present potential fire and explosion hazards. Multiple design features and standard management practices will be in place to ensure safe operation. These include: 1) reactor vessels designed (vessel wall construction, sensors, valves, and pressure regulators) to withstand temperatures and pressures at a margin of safety above that associated with normal operation, 2) incorporation of National Fire Protection Association recommended separations between flammable and explosive materials and possible sources of explosion/fire hazard, 3) contracting with major laboratory gas suppliers to ensure tanks and recharge operations comply with applicable safety standards, 4) computer monitoring and control of alarms and shutdown procedures, 4 and 5) manual shutdown overrides for situations where the computerized system could be compromised.

Upset: Aside from safety features noted above, facility design incorporates several features to eliminate risk of hazardous conditions resulting from operator error or unauthorized access. These include fencing, guard-attended gates, steel bollards to protect facilities from inadvertent vehicular damage, and provision of adequate maneuvering areas.

- **Solids Storage** - Wood chips will be delivered to the site and stored in a covered bin with approximate dimensions of 4 feet by 8 feet by 14 feet. Sand and kaolinite will be stored in the bags in which they are shipped, with about 20, 100-pound bags typically on-site. Catalysts (copper oxide, zinc oxide, manganese oxide and nickel oxide) will be stored on-site in 55-gallon drums (9 total).

- **Water Tank** - The steam component of the synthesized recycle gas feed will be generated from purified water. A 500 gallon tank will be placed on-site to receive deliveries by truck.
- **Methanol Storage** - A 1,000 gallon storage tank will be provided to store methanol produced in the on-site plant and to accept deliveries from outside sources as necessary to support fueling for CE-CERT vehicles. The proposed tank is a self-contained, above-ground structure with integrated fueling and emission control fixtures. The tank will be placed upon a pre-cast concrete pad that provides for containment in the event of a spill. Similar equipment is in use in the region and meets South Coast Air Quality Management District and Regional Water Quality Control Board permitting requirements. Once the fully integrated test system is operational, approximately 800 gallons of methanol would be generated by each test run.
- **Waste Storage** - Ash from the process vessels and solids from emission control filters will be stored on-site in standard 55-gallon drums until sufficient material is generated for off-hauling. About 15 drums of waste material could be removed each month.
- **Fencing** - The entire site will be enclosed by existing or proposed fencing, with access controlled through secured entry gates.
- **Lighting** - Portable lighting will be utilized for night-time operations during each test phase.
- **Control Room** - A small control room (about 300 square feet) will provide desk space for facility operators.
- **Surface Treatments** - Ground surfaces will consist of asphalt in parking and access areas and concrete in reactor pad and process areas. Berms and covers will be installed as necessary to minimize potential contaminants in stormwater discharges. This would include methanol handling areas (storage tank and pipe runs) and the compressor pad.

Permitting

Facility construction and operation will be subject to several permitting and regulatory programs. Based upon existing information, the following would apply:

South Coast Air Quality Management District - The methanol storage tank and combustion units may require permits from SCAQMD. The proposed storage tank is a prefabricated unit meeting SCAQMD requirements. The tank will be inspected prior to initial utilization and on an ongoing basis in accordance with SCAQMD permitting requirements. Combustion operations could be subject to several SCAQMD rules; burner emissions tests are presently being conducted to determine applicability.

Regional Water Quality Control Board - Site improvements will expose structures and materials handling areas to precipitation and alter the existing runoff patterns. An amendment to the existing stormwater pollution prevention plan for the Bourns site will be prepared and an amended notice of intent will be filed with the Regional Board.

Building Permits - Campus facilities are constructed under the review of campus planning and environmental health and safety officials. Plans will be reviewed for structural integrity and compliance with fire codes, and facility construction will be inspected by qualified campus officials.

Environmental Health and Safety - Facility design and operation is subject to more than 20 health and safety-related codes and standards including those promulgated by the

California Occupational Safety and Health Administration (pressure vessel certifications, boiler permits, process safety management plan), Uniform Fire Code and related National Fire Protection Association standards (flammable and combustible liquids, automotive and marine service stations, purged and pressurized electrical equipment enclosures, electrical installations in chemical process areas), Uniform Plumbing Code, Uniform Building Code, Uniform Mechanical Code, American National Standards Institute code for pressure piping, American Society of Mechanical Engineers code for boiler and pressure vessels, federal Occupational Safety and Health Administration regulations dealing with worker safety, federal Department of Transportation rules governing transport of compressed gases, and federal Environmental Protection Agency regulations governing hazardous material handling.

City of Riverside - Although the University is exempt from local planning and building authority, the campus will seek informal reviews by the City Planning and Fire departments.

Bourns, Inc. - Campus agreements with Bourns, Inc. require review and approval of facility utilization and development plans. Bourns review includes evaluation of improvement plans for compliance with Bourns' established health and safety programs. The emergency response and safety manuals for the methanol production facility will be incorporated into the plans for the overall Bourns site.

Funding

The proposed improvements will be funded through several sources including the United States Environmental Protection Agency, California Energy Commission and South Coast Air Quality Management District. Total cost for the proposed improvements and operation is approximately \$5.5 million.

Site Selection

Early planning efforts for the proposed facility included evaluation of a number of alternative locations. The following identifies these other sites and the reasons for their elimination in the site selection process.

Main UCR Campus - Two sites on the main campus were identified, one in the corporation yard and the other near the student housing area. These sites are both located in the northeast portion of the campus and were eliminated from further consideration due to: 1) conflicts with other campus facility needs, 2) incompatibility with existing and planned uses on campus and in adjacent off-campus areas, and 3) higher site improvement costs.

UCR Technology Center - An approximately 300 acre area east of the Bourns site is planned as a technology park that would support knowledge-intensive and high-tech industries, including industries arising from research conducted at the UCR campus. Lands within the technology park are currently undeveloped. The associated increased site improvement costs make a site within the technology park less favorable when compared to the proposed site.

Alternate Locations within the Bourns Site - Several locations within the Bourns site were considered prior to arriving at the proposed site. Accommodation of existing improvements, equipment maneuvering areas, recommended equipment separations, delivery access, and proximity to chemical storage and employee use areas at the Bourns plant, were all factors in selection of the proposed site.

Summary of Impacts

The environmental review and analysis contained herein indicates that the proposed project presents a potential for environmental impacts related to farmlands, geology, air quality and hazards. These impacts are summarized as follows:

- ***Farmlands***

The project site is designated as prime farmland. The magnitude of impact in this regard is considered insignificant due to the limited size of the site, ownership status as part of the Bourns property, fallow condition since the early 1960's, and existing and planned surrounding industrial use.

- ***Geology***

The reactor equipment is very heavy and can be subject to differential settlement or subsidence. Project-specific soils investigations (*UCR 1996*) have been conducted and specific recommendations for site preparation and foundation design have been incorporated as part of the proposed project. Established campus procedures ensure incorporation of recommended design features in site construction.

- ***Air Quality***

The proposed facility presents a limited number of potential sources of air emissions related to on-site material storage and process exhaust. Biomass and other solid materials represent a potential source of particulate emissions. Reactor system vents and exhaust represent potential sources of particulate and gaseous emissions. The proposed project includes storage enclosures, a closed reactor system design, and emission control equipment. Methanol storage will be in an SCAQMD-approved, prefabricated tank with integrated dispensing and emissions control features. The nature of raw materials utilized in the process ("white" wood chips¹, sand, clay, natural gas, and pure laboratory gases) eliminates the potential for toxic emissions.

Established campus planning programs ensure that necessary permits will be obtained from the South Coast Air Quality Management District prior to facility operation. It is possible that the facility will be exempt from SCAQMD permitting for combustion sources under provisions for research projects or small units.

Finally, it is noted that the primary goal of this project is development of a process that will provide a less-polluting alternate to petroleum-based fuels to reduce greenhouse gas emissions from mobile sources.

- ***Hazards***

Reactor design incorporates numerous safeguards to prevent explosions. The lack of existing or proposed residential development in the vicinity of the project site eliminates the hazard risk to adjacent residents. The lack of parks, schools and similar areas of congregation eliminates the hazard risk to the general public.

Federal and state worker safety regulations govern the siting of flammable and explosive materials relative to structures and workers at the Bourns site and in the surrounding industrial area. Proposed facility design and operation will comply with applicable standards of practice.

¹ White wood chips are from virgin sources that are not contaminated by preservatives or other chemicals that would potentially be found in recycled wood products.

Established campus procedures will require campus Fire Marshall approval of plans and inspection of finished facilities. The agreement between Bourns and the College of Engineering requires review and approval of facility design and operation protocols by Bourns' environmental safety officer.

The adjacent rail lines handle freight traffic of limited volume (three to five trains per week, typically 25 or fewer cars per train) on a straight, level alignment. The compound effect of limited potential for explosion or fire and the limited use of the rail lines, results in a minimal potential for safety hazards related to rail operations.

Determination

On the basis of this initial evaluation, it is determined that although the proposed project could potentially have significant effects on the environment, features included in the proposed project would avoid the impacts or reduce the effects to a point where clearly no significant effects would occur. A Negative Declaration will be prepared.

ENVIRONMENTAL CHECKLIST

A. PROJECT INFORMATION

1. Project Title:

Methanol Production Facility, UCR Project Number 958985-1

2. Lead Agency Name and Address:

University of California, Riverside
Office of Planning, Design and Construction
3615-A Canyon Crest Drive
Riverside CA 92507

3. Contact Person and Phone Number:

Tricia D. Thrasher, Senior Educational Facility Planner
(909) 787-4201, extension 618

4. Project Location: 1200 Columbia Avenue, Riverside

5. General Plan Designation: The project site is located within the boundaries of the Hunter Business Park Specific Plan. The plan designates the site for Industrial Park uses and describes a number of use and development standards that are discussed further in the response to checklist item 1, Land Use and Planning.

6. Zoning: The site is zoned MP-Manufacturing Park. See discussion of Item 1, Land Use and Planning.

B. ENVIRONMENTAL FACTORS POTENTIALLY AFFECTED:

The environmental factors checked below would be potentially affected by this project, involving at least one impact that is a "Potentially Significant Impact" as indicated by the checklist on the following pages.

- | | | |
|---|--|---|
| <input type="checkbox"/> Land Use and Planning | <input type="checkbox"/> Biological Resources | <input type="checkbox"/> Aesthetics |
| <input type="checkbox"/> Population and Housing | <input type="checkbox"/> Energy /Mineral Resources | <input type="checkbox"/> Cultural Resources |
| <input type="checkbox"/> Geologic Problems | <input type="checkbox"/> Hazards | <input type="checkbox"/> Recreation |
| <input type="checkbox"/> Water | <input type="checkbox"/> Noise | <input type="checkbox"/> Mandatory Findings of Significance |
| <input type="checkbox"/> Air Quality | <input type="checkbox"/> Public Services | <input checked="" type="checkbox"/> None of the Above |
| <input type="checkbox"/> Transportation/Circulation | <input type="checkbox"/> Utilities/Service Systems | |

c. EVALUATION OF ENVIRONMENTAL IMPACTS:

DIRECTIONS FOR EVALUATION OF ENVIRONMENTAL IMPACTS:

- 1) A BRIEF EXPLANATION IS REQUIRED FOR ALL ANSWERS EXCEPT "NO IMPACT" ANSWERS THAT ARE ADEQUATELY SUPPORTED BY THE INFORMATION SOURCES A LEAD AGENCY CITES IN THE PARENTHESES FOLLOWING EACH QUESTION. A "NO IMPACT" ANSWER IS ADEQUATELY SUPPORTED IF THE REFERENCED INFORMATION SOURCES SHOW THAT THE IMPACT SIMPLY DOES NOT APPLY TO PROJECTS LIKE THE ONE INVOLVED (E.G., THE PROJECT FALLS OUTSIDE A FAULT RUPTURE ZONE). A "NO IMPACT" ANSWER SHOULD BE EXPLAINED WHERE IT IS BASED ON PROJECT-SPECIFIC FACTORS AS WELL AS GENERAL STANDARDS (E.G., THE PROJECT WILL NOT EXPOSE SENSITIVE RECEPTORS TO POLLUTANTS, BASED ON A PROJECT-SPECIFIC SCREENING ANALYSIS).
- 2) ALL ANSWERS MUST TAKE ACCOUNT OF THE WHOLE ACTION INVOLVED, INCLUDING OFF-SITE AS WELL AS ON-SITE, CUMULATIVE AS WELL AS PROJECT-LEVEL, INDIRECT AS WELL AS DIRECT, AND CONSTRUCTION AS WELL AS OPERATIONAL IMPACTS.
- 3) "POTENTIALLY SIGNIFICANT IMPACT" IS APPROPRIATE IF THERE IS SUBSTANTIAL EVIDENCE THAT AN EFFECT IS SIGNIFICANT. IF THERE ARE ONE OR MORE "POTENTIALLY SIGNIFICANT IMPACT" ENTRIES WHEN THE DETERMINATION IS MADE, AN EIR IS REQUIRED.
- 4) "POTENTIALLY SIGNIFICANT UNLESS MITIGATION INCORPORATED" APPLIES WHERE THE INCORPORATION OF MITIGATION MEASURES HAS REDUCED AN EFFECT FROM "POTENTIALLY SIGNIFICANT IMPACT" TO A "LESS THAN SIGNIFICANT IMPACT." THE LEAD AGENCY MUST DESCRIBE THE MITIGATION MEASURES, AND BRIEFLY EXPLAIN HOW THEY REDUCE THE EFFECT TO A LESS THAN SIGNIFICANT LEVEL (MITIGATION MEASURES FROM SECTION 17, "EARLIER ANALYSES," MAY BE CROSS-REFERENCED).
- 5) EARLIER ANALYSES MAY BE USED WHERE, PURSUANT TO THE TIERING, PROGRAM EIR, OR OTHER CEQA PROCESS, AN EFFECT HAS BEEN ADEQUATELY ANALYZED IN AN EARLIER EIR OR NEGATIVE DECLARATION. REFERENCE: CEQA GUIDELINES SECTION 15063(C)(3)(D). EARLIER ANALYSES ARE DISCUSSED IN SECTION 17 AT THE END OF THE CHECKLIST.
- 6) LEAD AGENCIES ARE ENCOURAGED TO INCORPORATE INTO THE CHECKLIST REFERENCES TO INFORMATION SOURCES FOR POTENTIAL IMPACTS (E.G., GENERAL PLANS, ZONING ORDINANCES). REFERENCE TO A PREVIOUSLY PREPARED OR OUTSIDE DOCUMENT SHOULD, WHERE APPROPRIATE, INCLUDE A REFERENCE TO THE PAGE OR PAGES WHERE THE STATEMENT IS SUBSTANTIATED. SEE THE SAMPLE QUESTION BELOW. A SOURCE LIST SHOULD BE ATTACHED, AND OTHER SOURCES USED OR INDIVIDUALS CONTACTED SHOULD BE CITED IN THE DISCUSSION.

| Issues (and Supporting Information Sources): | Potentially Significant | | | |
|--|--------------------------------|--------------------------------|------------------------------|-------------------------------------|
| | Potentially Significant Impact | Unless Mitigation Incorporated | Less Than Significant Impact | No Impact |
| 1. LAND USE AND PLANNING. Would the proposal: | | | | |
| a) Conflict with general plan designation or zoning? (<i>Source: RIVCITY 1988, 1994 and 1994a</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| b) Conflict with applicable environmental plans or policies adopted by agencies with jurisdiction over the project? (<i>Source: RIVCITY 1988 and 1994</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| c) Be incompatible with existing land use in the vicinity? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |

| Issues (and Supporting Information Sources): | Potentially Significant Impact | Potentially Significant Unless Mitigation Incorporated | Less Than Significant Impact | No Impact |
|---|--------------------------------|--|-------------------------------------|-------------------------------------|
| d) Affect agricultural resources or operations (e.g., impacts to soils or farmlands, or impacts from incompatible land uses)? | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| e) Disrupt or divide the physical arrangement of an established community (including a low-income or minority community)? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| 2. POPULATION AND HOUSING. Would the proposal: | | | | |
| a) Cumulatively exceed official regional or local population projections? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| b) Induce substantial growth in an area either directly or indirectly (e.g., through projects in an undeveloped area or extension of major infrastructure)? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| c) Displace existing housing, especially affordable housing? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| 3. GEOLOGIC PROBLEMS. Would the proposal result in or expose people to potential impacts involving: | | | | |
| a) Fault rupture? (<i>Source: RIVCITY 1994, CDMG 1994</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| b) Seismic ground shaking? (<i>Source: RIVCITY 1994, CDMG 1994</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| c) Seismic ground failure, including liquefaction? (<i>Source: RIVCITY 1994, UCR 1996</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| d) Seiche, tsunami, or volcanic hazard? (<i>Source: Figure 2, CDMG 1994</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| e) Landslides or mudflows? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| f) Erosion, changes in topography or unstable soil conditions from excavation, grading, or fill? (<i>Source: UCR 1996</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| g) Subsidence of the land? (<i>Source: UCR 1996</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| h) Expansive soils? (<i>Source: UCR 1996</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |

| Issues (and Supporting Information Sources): | Potentially Significant Impact | Potentially Significant Unless Mitigation Incorporated | Less Than Significant Impact | No Impact |
|---|--------------------------------------|--|-------------------------------------|-------------------------------------|
| i) Unique geologic or physical features? (<i>Source: UCR 1996</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| 4. WATER. Would the proposal result in: | | | | |
| a) Changes in absorption rates, drainage patterns, or the rate and amount of surface runoff? | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| b) Exposure of people or property to water related hazards such as flooding? (<i>Source: FEMA 1983</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| c) Discharge into surface waters or other alteration of surface water quality (e.g., temperature, dissolved oxygen or turbidity)? | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| d) Changes in the amount of surface water in any water body? | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| e) Changes in currents, or the course or direction of water movements? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| f) Changes in the quantity of ground waters, either through direct additions or withdrawals, or through interception of an aquifer by cuts or excavations or through substantial loss of groundwater recharge capability? (<i>Source: UCR 1996</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| g) Altered direction or rate of flow of groundwater? (<i>Source: UCR 1996</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| h) Impacts to groundwater quality? (<i>Source: UCR 1996</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| i) Substantial reduction in the amount of groundwater otherwise available for public water supplies? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| 5. AIR QUALITY. Would the proposal: | | | | |
| a) Violate any air quality standard or contribute to an existing or projected air quality violation? (<i>Source: SCAQMD 1993</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| b) Expose sensitive receptors to pollutants? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| c) Alter air movement, moisture, or temperature, or cause any change in climate? | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> |

| Issues (and Supporting Information Sources): | Potentially Significant Impact | Potentially Significant Unless Mitigation Incorporated | Less Than Significant Impact | No Impact |
|---|--------------------------------------|--|-------------------------------------|-------------------------------------|
| d) Create objectionable odors? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| 6. TRANSPORTATION/CIRCULATION. | | | | |
| Would the proposal result in: | | | | |
| a) Increased vehicle trips or traffic congestion? | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| b) Hazards to safety from design features (e.g., sharp curves or dangerous intersections) or incompatible uses (e.g., farm equipment)? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| c) Inadequate emergency access or access to nearby uses? (<i>Source: Figures 2 and 3</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| d) Insufficient parking capacity on-site or off-site? (<i>Source: Figures 2 and 3</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| e) Hazards or barriers for pedestrians or bicyclists? (<i>Source: Figures 2 and 3</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| f) Conflicts with adopted policies supporting alternative transportation (e.g., bus turnouts, bicycle racks)? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| g) Rail, waterborne or air traffic impacts? (<i>Source: RIVCITY 1994, Figure 2</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| 7. BIOLOGICAL RESOURCES. Would the proposal result in impacts to: | | | | |
| a) Endangered, threatened or rare species or their habitats (including but not limited to plants, fish, insects, animals, and birds)? (<i>Source: Figure 2</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| b) Locally designated species (e.g., heritage trees)? (<i>Source: RIVCITY 1994</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| c) Locally designated natural communities (e.g., oak forest, coastal habitat, etc.)? (<i>Source: RIVCITY 1994</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| d) Wetland habitat (e.g., marsh, riparian and vernal pool)? (<i>Source: Figure 2</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| e) Wildlife dispersal or migration corridors? (<i>Source: Figure 2</i>) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |

| Issues (and Supporting Information Sources): | Potentially Significant Impact | Potentially Significant Unless Mitigation Incorporated | Less Than Significant Impact | No Impact |
|--|--------------------------------------|--|------------------------------------|--------------|
|--|--------------------------------------|--|------------------------------------|--------------|

8. ENERGY AND MINERAL RESOURCES.

Would the proposal:

- | | | | | |
|---|--------------------------|--------------------------|--------------------------|-------------------------------------|
| a) Conflict with adopted energy conservation plans? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| b) Use non-renewable resources in a wasteful and inefficient manner? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| c) Result in the loss of availability of a known mineral resource that would be of future value to the region and the residents of the state? (Source: RIVCITY 1994) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |

9. HAZARDS. Would the proposal involve:

- | | | | | |
|--|--------------------------|--------------------------|-------------------------------------|-------------------------------------|
| a) A risk of accidental explosion or release of hazardous substances (including, but not limited to, oil, pesticides, chemicals or radiation)? | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| b) Possible interference with an emergency response plan or emergency evacuation plan? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| c) The creation of any health hazard or potential health hazard? | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| d) Exposure of people to existing sources of potential health hazards? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| e) Increased fire hazard in areas with flammable brush, grass, or trees? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |

10. NOISE. Would the proposal result in:

- | | | | | |
|---|--------------------------|--------------------------|-------------------------------------|-------------------------------------|
| a) Increases in existing noise levels? | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| b) Exposure of people to severe noise levels? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |

11. PUBLIC SERVICES. Would the proposal have an effect upon, or result in a need for new or altered government services in any of the following areas:

- | | | | | |
|-----------------------|--------------------------|--------------------------|-------------------------------------|-------------------------------------|
| a) Fire protection? | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| b) Police protection? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |

| Issues (and Supporting Information Sources): | Potentially Significant Impact | Potentially Significant Unless Mitigation Incorporated | Less Than Significant Impact | No Impact |
|---|--------------------------------------|--|-------------------------------------|-------------------------------------|
| c) Schools? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| d) Maintenance of public facilities, including roads? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| e) Other governmental services? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| 12. UTILITIES AND SERVICE SYSTEMS. | | | | |
| Would the proposal result in a need for new systems or supplies, or substantial alterations to the following utilities: | | | | |
| a) Power or natural gas? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| b) Communications systems? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| c) Local or regional water treatment or distribution facilities? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| d) Sewer or septic tanks? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| e) Storm water drainage? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| f) Solid waste disposal? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| g) Local or regional water supplies? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| 13. AESTHETICS. Would the proposal: | | | | |
| a) Affect a scenic vista or scenic highway? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| b) Have a demonstrable negative aesthetic effect? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| c) Create light or glare? | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
| 14. CULTURAL RESOURCES. Would the proposal: | | | | |
| a) Disturb paleontological resources? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| b) Disturb archaeological resources? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| c) Affect historical resources? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| d) Have the potential to cause a physical change which would affect unique ethnic cultural values? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |

| Issues (and Supporting Information Sources): | Potentially Significant Impact | Potentially Significant Unless Mitigation Incorporated | Less Than Significant Impact | No Impact |
|---|--------------------------------------|--|------------------------------------|-------------------------------------|
| e) Restrict existing religious or sacred uses within the potential impact area? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| 15. RECREATION. Would the proposal: | | | | |
| a) Increase the demand for neighborhood or regional parks or other recreational facilities? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| b) Affect existing recreational opportunities? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| 16. MANDATORY FINDINGS OF SIGNIFICANCE | | | | |
| a) Does the project have the potential to degrade the quality of the environment, substantially reduce the habitat of a fish or wildlife species, cause a fish or wildlife population to drop below self-sustaining levels, threaten to eliminate a plant or animal community, reduce the number or restrict the range of a rare or endangered plant or animal, or eliminate important examples of the major periods of California history or prehistory? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| b) Does the project have the potential to achieve short-term, to the disadvantage of long-term, environmental goals? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| c) Does the project have impacts that are individually limited, but cumulatively considerable? ("Cumulatively considerable" means that the incremental effects of a project are considerable when viewed in connection with the effects of past projects, the effects of other current projects, and the effects of probable future projects.) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| d) Does the project have environmental effects which will cause substantial adverse effects on human beings, either directly or indirectly? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |

DISCUSSION OF ENVIRONMENTAL EVALUATION

This section provides an explanation for the impact level category indicated for each issue area in the preceding checklist. Where applicable, this section also describes features incorporated into the proposed project, established review and permitting programs, and/or specific mitigation measures proposed to lessen potential impacts of the proposed project.

1. Land Use and Planning

a, c. Potential Land Use Conflict. The Hunter Business Park Specific Plan provides the guiding land use criteria for development of the project site. The project site is within an area designated for Industrial Park uses. Uses related to scientific research, including fabrication and testing of prototypes, are among the intended uses for the Industrial Park district. The proposed location meets all of the parcel size, setback and building height criteria stipulated for the Industrial Park district.

The immediately surrounding area is characterized by the Bourns plant to the west, vacant land and citrus groves to the south, a rail line and vacant land to the east, and citrus groves and industrial park uses to the north. The larger surrounding setting is characterized by existing and developing industrial park uses within Hunter Business Park. The nearest residential development is located approximately one mile to the southeast along the base of Sugarloaf Mountain. The proposed location does not create any new conditions that raise a potential for compatibility conflicts with existing or proposed land uses.

See related discussions under items 6, Transportation/Circulation, 9, Hazards and 13, Aesthetics.

b. Conflict with Environmental Plans/Policies. There are no land-based environmental resources that will be directly impacted by proposed construction. Facility operation will be subject to established permitting procedures of the South Coast Air Quality Management District relative to potential air emissions, and will also be subject to review by the California Regional Water Quality Control Board relative to stormwater discharges. Emission control equipment included as part of the project provides for compliance with SCAQMD requirements and enclosures, covers, and surface treatments (grading, berms, impervious surfaces) provide for compliance with stormwater regulations.

See related discussions of items 4, Water, and 5, Air.

d. Agricultural Lands. The City of Riverside General Plan recognizes the soils on the project site as Prime Farmlands, based upon mapping administered by the California Department of Conservation. The site is part of an established industrial operation and is an approximately 0.4 acre portion of an approximately 4 acre undeveloped area between the existing Bourns factory buildings and the AT&SF railroad lines.

This small site has been fallow since removal of the citrus groves with construction of the Bourns facility in the 1960's. Considering its size, ownership, and surrounding development, the site does not represent a viable commercial agricultural opportunity. As noted above, the proposed use is consistent with the industrial land use designation under the City General Plan.

e. Community Disruption. The proposed improvements and activities will take place at a site within the interior of an established industrial site, within a larger established industrial

district. The potential for impacts to the physical arrangement of the surrounding community does not exist.

2. Population and Housing

The proposed improvements and activities involve a research project that will largely rely upon existing staff resources. The project will not result in any direct increase in population, housing or employment.

3. Geologic Problems

a,b,c,d. Seismic. There are no known faults on the project site. The site is located within a seismically active region in which severe groundshaking can be expected. Established design criteria contained in the Uniform Building Code require that facility construction incorporate features to minimize damage in the event of a seismic event. Established campus procedures for facility design and construction ensure incorporation of standard seismic safety features.

Soils testing in support of facility design included borings to depth of 30 feet, in which no groundwater was encountered. The absence of near surface groundwater eliminates the potential for liquefaction. Similarly, the site is not exposed to water bodies that would present the potential for seiche or tsunami hazards, nor are there any known volcanic resources in the immediate area.

e. Landslides. The level topography characterizing the project site and surrounding area does not present the potential for landslides or mudflows.

f. Erosion. Preparation of the project site for structure foundations and new surfaces will require grading. During the grading phase, site soils will be subject to wind and water erosion. The limited size of the building site, gentle topography, and finished site conditions limit the potential for significant erosion impacts.

g,h,i. Stability/Unique Features. The proposed reactor facilities are heavy and require enhanced foundations to eliminate the potential for subsidence or uneven settling. A site-specific soils investigation has been completed and recommendations for foundation design have been provided to the design engineer. Established campus design and construction procedures ensure incorporation of such recommendations.

The lack of groundwater at the project site eliminates the risk of subsidence impacts to the larger surrounding area.

The site-specific soils investigation concluded that site soils are not expansive in nature.

There are no unique geologic or physical features at the project site.

4. Water

a. Drainage. The proposed improvements will create an additional impervious surface area of approximately 0.4 acres. This will result in a minor increase in the rate of runoff from the newly improved area and a minor increase in the amount of surface water generated at the Bourns site. Site improvements will maintain existing drainage patterns. Runoff will continue to be directed into the existing flow line along the south boundary of the Bourns site and existing catch basins in the adjacent Bourns site outdoor work areas.

b. Flooding. The project site is not in an area which is subject to flood hazard and the proposed improvements do not contain any components that present a potential flood hazard to surrounding properties.

c,d,e. Surface Waters. Runoff from the project site enters the City storm drain system and eventually is discharged to the Santa Ana River. The types of activities to be conducted at the site present the potential for discharge of particulates (raw materials, ash, dust from structures), grease and oil (vehicles, compressors and other mechanical equipment), and methanol (storage tank and pipelines) in site runoff. Best management practices identified in industry-wide general stormwater permits include: 1) exposure minimization practices such as covers, berms and dikes, 2) detention/filtration facilities, and 3) good housekeeping, including material storage and handling procedures, inspections, spill prevention, and spill response. Considering the size of the project site, the nature and volume of materials potentially exposed, campus Environmental Health and Safety requirements for procedure manuals, and proposed site improvements (storage containers, covers, and berms), the potential for discharge of contaminants in site runoff is minimal. An amendment to the existing stormwater pollution prevention plan for the Bourns facility and a revised notice of intent for coverage under the State General NPDES permit for industrial stormwater discharges will be prepared.

f,g,h,i. Groundwater. No groundwater was encountered in the project-specific geotechnical investigations.

5. Air Quality

a,b. Emissions. The proposed facility presents a limited number of potential sources of air emissions related to on-site material storage and process exhaust. Biomass and other solid materials represent a potential source of particulate emissions. Storage enclosures for solid materials are incorporated into project design. The biomass feed system vent is also equipped with filters to capture particulates.

Reactor system vents and exhaust represent potential sources of particulate and gaseous emissions. The nature of the proposed process and internal controls required for successful methanol production serve to control these potential emission sources. The integrated system is an closed loop with exhaust limited to those gases vented from the system when the reactor is shut down. Particulate and sulfur control is an integral component of the system; product gas from the HPR is screened for particulates and sulfur (a minor component of the natural gas feed that initiates the reaction), providing for clean process gas for the reactions that take place in the SPR and MSR reactors. All vents and exhaust streams are piped to the flare unit, where exhaust gas is burned to produce carbon dioxide, water and trace amounts of carbon monoxide and oxides of nitrogen. Operation of the flare is similar to the operation of the burner in a residential gas water heater. Considering the size and nature of the proposed operation, potential emissions will be considerably below the SCAQMD's thresholds of 55 pounds per day of reactive organic compounds, 55 pounds per day of oxides of nitrogen, 550 pounds per day of carbon monoxide, 150 pounds per day of particulates, and 150 pounds per day of oxides of sulfur.

The nature of the raw materials utilized in the process (wood chips, sand, clay, natural gas, and pure laboratory gases) eliminates the potential for toxic emissions. It is also noted that the SCAQMD procedure for evaluation of toxic hazards utilizes a radius of one-fourth mile from a potential source for identification of potential sensitive receptors. Even if toxic emissions was a potential issue, there are no potential sensitive receptors within one-fourth mile of the project site.

The proposed methanol storage tank is a prefabricated unit with integral vapor recovery controls on the tank and pumps.

Necessary permits will be obtained from the South Coast Air Quality Management District prior to facility operation. It is possible that the reactor unit will be exempt from SCAQMD permitting under provisions for research projects or small combustion units.

Finally, it is noted that the primary goal of this project is development of a process that will provide a less-polluting alternative to petroleum-based fuels to reduce greenhouse gas emissions from mobile sources, by means of a process which itself is less-polluting than current technologies for methanol production.

c. Climate. During operation phases, elevated temperatures will be experienced in the immediate vicinity of the reactor vessels and the flare. However, the limited scale and periodic occurrence of facility operation result in a magnitude and duration that would not affect climatic conditions.

d. Odors. Sulfur is a minor component of natural gas, which is one of the raw materials used in the proposed process. The presence of sulfur creates the potential for formation of hydrogen sulfide gas, which creates a characteristic smell of rotten eggs. However, as noted above, the removal of sulfur by adsorption in the closed reactor system is an integral component of the process. The project does not present the potential for exposure of the public to objectionable odors.

6. Transportation/Circulation

a. Capacity/Access. Facility operation will involve a limited number of truck trips associated with delivery of materials and removal of wastes. The estimated maximum 40 trips per month is an insignificant increment to the existing road network serving this developed industrial site.

b,c,e. Hazards. The site is served by an existing street network and access points on the Bourns site. The site is not affected by any design features or incompatible uses that present potential traffic movement conflicts. Facility layout has taken into account maneuvering areas required for material delivery and phased installation of equipment, as well as protection of equipment from accidental damage by vehicles and protection of delivery and emergency access routes for Bourns' operations. Improvements will not affect areas associated with pedestrian or bicycle use.

d. Parking. More than sufficient parking is available in the existing Bourns lot.

f. Alternate Transportation. The proposed improvements do not affect any existing alternative transportation improvements, nor would they preclude, any planned improvements or programs related to alternative transportation.

g. Rail, Waterborne, and Air Traffic. A rail line runs along the east boundary of the Bourns site, approximately 100 feet east of the proposed site of the methanol production facility. The proposed improvements will not directly impact the existing rail lines or associated right-of-way.

The rail line at this location is a straight, level alignment on a rail bed that is elevated approximately 5 to 10 feet above the elevation of the proposed improvements. The proposed tank storage area and methanol synthesis reactor facility are located approximately

125 feet from the rail lines. The gasification reactor (HPR and SPR units) is located approximately 250 feet from the rail lines. This distance, combined with the slow speed and minor volume of traffic on this particular rail line, does not represent a significant exposure to damage from, or to, the rail lines.

See item 9a for discussion of potential impacts related to storage of flammable and explosive materials.

7. Biological Resources

The project site is an undeveloped portion of an established industrial site, within a larger surrounding area characterized by industrial development and citrus groves. Site vegetation consists of a sparse cover of non-native grasses and herbaceous plants. The site does not provide potential habitat for any endangered, threatened, rare, or locally designated species.

8. Energy/Mineral Resources

a. Energy Conservation. The proposed project does not consume inordinate quantities of energy (see item 12). In fact, the proposed project is in support of national energy goals to develop liquid fuels utilizing native, renewable resources to replace petroleum-based fuels.

b. Non-renewable Resources. Construction and operation of the proposed facility will require building materials and process materials derived from non-renewable resources. However, the type and quantities of materials required and the scale of the proposed operation do not require resources in amounts that would substantially affect available supply.

c. Mineral Resources. The project site is not within a designated mineral resource zone.

9. Hazards

a. Explosion/Hazardous Substance Release. Reactor design incorporates numerous safeguards to prevent explosions. Pressure regulators and relief valves are installed on inlet gas lines and the reactor vessels. Temperature sensors and regulators automatically shut down operations if temperatures get too high. Nitrogen gas fills the vented reactor vessels and vented gases are burned in a flare.

Process materials include pressurized gases. Of the gases to be stored on-site, only hydrogen is characterized as a hazardous gas. National Fire Protection Association (NFPA) guidelines identify acceptable separation distances for protection of residential areas and areas of anticipated human congregation, such as parks. For pressurized gases, separation distances are determined for both fire and explosion hazards. For the proposed project, the hydrogen gas would be stored in a container with a volume of approximately 5,500 gallons (water capacity). For this size of container, the NFPA guidelines recommend a separation of 390 feet for explosive hazard, 110 feet for protection of buildings from heat due to a fire, and 560 feet for protection of persons from heat due to a fire. The NFPA criteria are specifically directed at protecting residential wood frame structures and public congregation areas from fire and explosive hazards presented by encroaching industrial development. The lack of existing or proposed residential development in the vicinity of the project site eliminates the hazard risk to adjacent residents. The lack of parks, schools and similar areas of congregation eliminates the hazard risk to the general public.

Methanol will be stored on-site in a 1,000 gallon above-ground tank. Methanol is a flammable liquid. Because it is not stored under pressure, the exposure risk is limited to fire. NFPA guidelines recommend a separation of 70 feet for structures and 360 feet for people. As with pressurized gas storage, the lack of existing or proposed residential development and the lack of parks, schools and similar areas of congregation eliminates the hazard risk to residents and the general public.

Federal and state worker safety regulations govern the siting of flammable and explosive materials relative to structures and workers at the Bourns site. The separation provided by the proposed tank parking site and the orientation of the tanks on an alignment parallel to the building have been reviewed and determined appropriate by both campus and Bourns' safety personnel.

The adjacent rail lines handle freight traffic of limited volume (three to five trains per week, typically 25 or fewer cars per train). The compound effect of limited potential for explosion or fire and the limited use of the rail lines, present a minimal potential for safety hazards related to proximity to rail facilities.

b. Emergency Response. The proposed improvements will not affect any existing emergency response or evacuation routes.

c,d. Health Hazard. Methanol is toxic if ingested orally and prolonged or high concentration exposure to vapors can cause irritation of the eyes, skin and respiratory tract. Occupational exposure is regulated by the Occupational Safety and Health Administration. Security measures, storage and dispensing equipment features, standard operating practices, and the isolated location of the proposed facility minimize the potential risk of exposure to the general public.

e. Fire Hazard. There are no open grasslands, shrublands or forests in the potentially-affected surrounding area.

10. Noise

Facility operation will involve the use of compressors and mechanical components that will result in perceptible increases in noise levels in the immediate area. Established safety regulations will provide for protection of facility workers; the lack of nearby sensitive receptors (residential uses, schools, open space/recreational uses) eliminates noise impacts as a potential issue for the surrounding area.

11. Public Services

a. Fire Protection. The project site is served by an existing City of Riverside fire station in the vicinity of Linden and Iowa Avenues, approximately 1-1/2 miles to the southwest, and an existing Riverside County fire station in the vicinity of Center Street and Iowa Avenue, approximately one mile to the north.

Facility design incorporates reactor vessels and pipelines designed in accordance with NFPA, ANSI and ASME standards. Shut-off valves are provided to interrupt process flows (either in automated or manual modes) at critical points if needed in an emergency.

Code requirements establish a minimum fire flow of 1,500 gallons per minute. Standard campus review procedures will ensure establishment of sufficient fire flow at the proposed plant. Water can be provided from the existing service to the Bourns site or existing mains in Columbia and Iowa Avenues.

b,c,e. Other Public Services. Addition of the proposed improvements at the existing Bourns site will not generate additional demand for police services. The project does not involve substantial new employment that would affect local schools nor does the project present the potential for significant impacts to any other governmental services.

d. Public Facility Maintenance. The proposed project does not include any new public improvements. The operational characteristics of the proposed facility will not result in substantial additional demand upon existing public facilities.

12. Utilities/Service Systems

a. Power/Natural Gas. Service is available at the project site. The proposed facility will consume approximately 10,500 kilowatts of electricity and 120,000 cubic feet of natural gas in each test run. This is equivalent to the amount of energy consumed by 20 average single-family residences and does not represent a substantial demand that would require system improvements or supply development.

b. Communications Systems. Service is available at the project site.

c,g. Water. Purified water will be delivered by truck and stored in a 500 gallon tank. Purified water will be used for generation of steam that makes up part of the synthesis gas stream. Additional water from the City system will also be required for cooling. A total of approximately 1,325 gallons of water is required for each test run. Over a one-year period, total water consumption would be equivalent to that used by one single-family residence in approximately 80 days. This amount does not represent a substantial demand that would require system improvements or supply development.

Water can be provided from the existing service lines to the Bourns site or an extension from the existing mains in Iowa and Columbia Avenues. Either of these options would involve comparatively minor trenching through disturbed areas.

d. Sewer. The project does not involve any new discharges to the City sewer system. Sanitary facilities are available at the existing CE-CERT offices.

e. Storm Drains. The approximately 0.4 acres of additional impervious surface area that will be created as part of the proposed project represents an insignificant increment to flows already directed to the existing storm drains in Iowa and Columbia Avenues.

e. Solid Waste Disposal. Solid waste generated by the proposed facility will consist of ash and bed material removed from the HPR reactor, filter residues and spent catalyst. Reactor bed and filter residue will generate approximately 15, 55-gallon drums of waste each month. Depending upon the results of toxicity testing, these wastes will either be disposed of at the local sanitary landfill, or disposed of under contract by a licensed hazardous material handler. The limited quantities do not represent a significant demand upon available landfill space.

13. Aesthetics

a,b. Visual Effects. The project site is not visible from any scenic highway or scenic vista. The site is largely shielded from public view by the existing building and landscaping at the Bourns site. Although the site is visible from Columbia Avenue immediately north of the site, this is not a designated scenic corridor and the appearance of the proposed

improvements is not inconsistent with existing accessory improvements at the Bourns site and other industrial plants in the larger Hunter Business park area.

c. Light and Glare. Portable lights will be used during night operations for the duration of each test run. Considering the lack of sensitive receptors in the surrounding area, this is not a significant issue.

14. Cultural Resources

The project site is located within an established industrial park in an area that had been in citrus production prior to industrial use. There is no visible evidence of historic structures on the site. Historic disturbance in the area results in limited potential for subsurface artifacts. The local geologic formation is not known to be fossil-bearing. There are no known resources of ethnic or religious significance within the project impact area.

15. Recreation

The project site is within an existing industrial plant. The proposed project will not directly impact any existing recreational opportunities.

The facility will be staffed primarily by existing CE-CERT researchers. The proposed project will not increase the demand for recreational facilities.

16. Mandatory Findings of Significance

a. Environmental Degradation, Sensitive Species, Cultural Resources. The proposed project, by its nature, scale and location, does not present the potential for significant environmental degradation. The project will not affect any known biological or cultural resources.

b. Short-term versus Long-term. The project does not present the potential for significant short-term impacts and is in furtherance of long-term environmental goals to reduce emissions resulting from reliance upon petroleum-based fuels.

c. Cumulative Impacts. No cumulative impacts have been identified. Individual potential impacts identified in the preceding evaluation with respect to farmlands, subsidence, air emissions and safety hazards are all addressed by established regulatory programs or aspects of the project design and setting.

d. Adverse Human Effects. Limited potential for air emissions and explosion hazards have been identified in the preceding analysis. However, the lack of residential development, recreational uses or similar areas for human congregation eliminates the potential for substantial adverse effects on human beings.

LEAD AGENCY DETERMINATION

On the basis of this initial evaluation:

I find that the proposed project COULD NOT have a significant effect on the environment, and a NEGATIVE DECLARATION will be prepared. ☒

I find that although the proposed project could have a significant effect on the environment, there will not be a significant effect in this case because the mitigation measures described on an attached sheet have been added to the project. A NEGATIVE DECLARATION will be prepared..... ☐

I find that the proposed project MAY have a significant effect on the environment, and an ENVIRONMENTAL IMPACT REPORT is required. ☐

I find that the proposed project MAY have a significant effect(s) on the environment, but at least one effect (1) has been adequately analyzed in an earlier document pursuant to applicable legal standards, and (2) has been addressed by mitigation measures based on the earlier analysis as described on attached sheets, if the effect is a "potentially significant impact" or "potentially significant unless mitigated." An ENVIRONMENTAL IMPACT REPORT is required, but it must analyze only the effects that remain to be addressed. ☐

I find that although the proposed project could have a significant effect on the environment, there WILL NOT be a significant effect in this case because all potentially significant effects (1) have been analyzed adequately in an earlier EIR pursuant to applicable standards and (2) have been avoided or mitigated pursuant to that earlier EIR, including revisions or mitigation measures that are imposed upon the proposed project..... ☐

Tricia D. Thrasher
Signature

JULY 12, 1996
Date

TRICIA D. THRASHER
Printed Name

UNIVERSITY OF CALIFORNIA,
For RIVERSIDE

REFERENCES

The following documents were consulted in preparation of this initial study. The location where each document can be obtained for review is indicated in each entry. The notes at the bottom of this section provide the address of each individual location.

- | | |
|----------------------|---|
| <i>Acurex 1994</i> | Methanol Production from the Hynol Process Using Biomass Feedstock - Facility, Safety, Permitting, and Materials Management Requirements, Acurex Environmental Corporation, dated November 25, 1994. <i>Available at CE-CERT.</i> |
| <i>Acurex 1995</i> | Evaluation of a Process to Convert Biomass to Methanol Fuel - Work Plan, Bourns College of Engineering and Acurex Environmental Corporation, dated August 1995. <i>Available at CE-CERT.</i> |
| <i>Acurex 1995a</i> | Hynol Process Engineering - Process Configuration, Site Plan and Equipment Design, Acurex Environmental Corporation, dated April 27, 1995. <i>Available at CE-CERT.</i> |
| <i>CDMG 1994</i> | Fault Activity Map of California and Adjacent Areas, California Department of Conservation Division of Mines and Geology, dated 1994. <i>Available at Webb.</i> |
| <i>FEMA 1983</i> | Flood Insurance Rate Maps Panel No. 060260 005 A, Federal Emergency Management Agency, dated January 6, 1983. <i>Available at City.</i> |
| <i>RIVCITY 1988</i> | Hunter Business Park Specific Plan, City of Riverside Planning Department, dated August 1988 as amended through 1990. <i>Available at City.</i> |
| <i>RIVCITY 1994</i> | City of Riverside General Plan, City of Riverside Planning Department, dated September 13, 1994. <i>Available at City.</i> |
| <i>RIVCITY 1994a</i> | Title 19 - Zoning Code of the City of Riverside, City of Riverside Planning Department, dated November 1994. <i>Available at City.</i> |
| <i>RIVCO 1991</i> | Gateway Center Specific Plan and EIR Technical Appendices, County of Riverside, dated October 1991. <i>Available at County.</i> |
| <i>SCAQMD 1993</i> | South Coast Air Quality Management District, Air Quality Handbook for Preparation of Environmental Impact Reports, Revised November 1993. <i>Available at SCAQMD.</i> |
| <i>UCR 1991</i> | Procedural Handbook and Model Approach for Implementing the California Environmental Quality Act, University of California, dated May, 1991. <i>Available at Campus Planning.</i> |
| <i>UCR 1996</i> | Preliminary Soils Investigation, UCR CE-CERT Biomass to Methanol Fuel Plant (Project No. 20742.1), LOR Geotechnical, dated February 1996. <i>Available at CE-CERT.</i> |

| | |
|------------------------|--|
| <i>USEPA 1994</i> | Chemical Summary for Methanol, prepared by Office of Pollution Prevention and Toxics (EPA 749-F-94-013a), U.S. Environmental Protection Agency, dated August 1994. <i>Available at Webb.</i> |
| <i>USEPA 1994a</i> | Fact Sheet OMS-7, Methanol Basics (EPA 400-F-92-009), U.S. Environmental Protection Agency, dated August 1994. <i>Available at Webb.</i> |
| <i>USEPA 1994b</i> | Fact Sheet OMS-8, Methanol Fuels and Fire Safety (EPA 400-F-92-010), U.S. Environmental Protection Agency, dated August 1994. <i>Available at Webb.</i> |
| <i>USEPA 1994c</i> | OPPT Chemical Fact Sheet, Chemicals in the Environment: Methanol (EPA 749-F-94-013), Office of Pollution Prevention and Toxics, U.S. Environmental Protection Agency, dated August 1994. <i>Available at Webb.</i> |
| <i>USHUD</i> | Siting of HUD-Assisted Projects Near Hazardous Facilities - A Guidebook, U.S. Department of Housing and Urban Development, undated. <i>Available at Webb.</i> |
| <u>Location:</u> | <u>Address:</u> |
| <i>Campus Planning</i> | University of California, Riverside Office of Planning, Design and Construction, 3615 A Canyon Crest Drive, Suite D-102, Riverside. |
| <i>CE-CERT</i> | University of California, Riverside Center for Environmental Research and Technology, 1200 Columbia Avenue, Riverside. |
| <i>City</i> | City of Riverside Planning Department, 3900 Main Street, Riverside. |
| <i>County</i> | County of Riverside Planning Department, 4080 Lemon Street, Riverside |
| <i>SCAQMD</i> | South Coast Air Quality Management District, 21865 East Copley Drive, Diamond Bar, CA 91765-4182 |
| <i>Webb</i> | Albert A. Webb Associates, 3788 McCray Street, Riverside. |

Appendix II

Preliminary Soils Investigation

UCR, CE-CERT, Biomass to Methanol Fuel Plant

Bourns, Inc., Facility
1200 Columbia Avenue
Riverside, California

Project No.: 20742.1
February 12, 1996

LOR Geotechnical Group, Inc.
6121 Quail Valley Court
Riverside, CA 92507
(909) 653-1760
Fax (909) 653-1741

Prepared for:

Dagostino Engineering
329 West State Street, Suite A-2
Redlands, CA 92373

Attention: Mr. Keith Dagostino

LOR **GEOTECHNICAL GROUP, INC.**
Soil Engineering ▲ Geology ▲ Environmental

February 12, 1996

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329 West State Street, Suite A-2
Redlands, California 92373

Attention: Mr. Keith Dagostino


Gentlemen:

Transmitted with this letter is our report entitled Preliminary Soils Investigation, UCR, CE-CERT Biomass to Methanol Fuel Plant, Bourns Inc. Facility, 1200 Columbia Avenue, Riverside, California prepared for Dagostino Engineering, Project No. 20742.1.

This report was based upon a scope of services generally outlined in our Proposal Letter dated November 21, 1995 and in other written and verbal communications with your office.

It has been our pleasure assisting you on this project. If you have any questions or comments concerning the information in this report, please contact us.

Respectfully submitted,
LOR Geotechnical Group, Inc.



John P. Leuer, GE
President

JLG:sju

Distribution: Addressee (6)

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INTRODUCTION

During February of 1996, LOR Geotechnical Group Inc. conducted a Preliminary Soils Investigation for the proposed UCR, CE-CERT Biomass to Methanol Fuel Plant located at 1200 Columbia Avenue, Riverside, California. The purpose of this investigation was to evaluate the subsurface soil conditions encountered in our exploratory borings, and based on that evaluation, provide geotechnical design recommendations for the proposed development from a soil engineering point of view. The scope of our services included: 1) A subsurface field investigation; 2) Laboratory testing of selected soil samples obtained during the field investigation; 3) Development of geotechnical recommendations for site grading and foundation design; and 4) Preparation of this report.

To orient our investigation at the site, a 20-scale Site Plan was furnished for our use. The proposed building and equipment locations were indicated on this plan.

The findings of our investigation, as well as our conclusions and recommendations, are presented in the following sections of this report.

PROJECT CONSIDERATIONS

The approximate location of the site is shown on the attached Index Map, Enclosure A-1 within Appendix A.

Information furnished this firm indicates the proposed project is a biomass to methanol fuel plant which will consist of a gasification reactor, a control room, as well as assorted storage tanks, compressors and related equipment. The assorted structures are anticipated to be constructed of steel, concrete and masonry type materials supported by spread foundations. Light to moderate foundation loads are anticipated with such structures.

No grading plan was available for our use during this investigation. However, observation of the site topography and adjacent properties indicates site development will entail minimal cuts and fills.

EXISTING SITE CONDITIONS

The proposed plant is to be located in the southeast corner of the Bourns Inc. facility on the southeast corner of Columbia Avenue and Iowa Avenue in the city of Riverside. The site topography generally consisted of two levels, with the southwest corner raised approximately three feet higher and a slight overall slope to the north. The site was generally vacant except for a storage container, a steel tank and assorted piles of fencing materials and metal scrap. The west half of the site is enclosed by a chain link fence, and had evidence of recently placed, uncompacted, fill placed across the majority of the parcel. The vegetation on the site consisted of a light growth of weeds, with the easterly, unfenced portion of the site being recently disced. Adjacent to the site to the west and northwest are various structures associated with the Bourns Inc. facility and UCR Methonal Research Operations. To the south, east and northeast of the site is vacant property and a set of railroad tracks.

FIELD INVESTIGATION

Our field exploration program was conducted on February 1, 1996 and consisted of drilling five exploratory borings with a truck-mounted CME 55 drill rig equipped with 8-inch diameter hollow stem augers. The borings were drilled to depths ranging from 23.5-feet to 30.0-feet. The approximate locations of our exploratory borings are presented on the attached Plat, Enclosure A-2 within Appendix A.

Logs of the subsurface conditions encountered in the exploratory borings were maintained by a geologist from this firm. Relatively undisturbed and bulk samples were obtained at a maximum depth interval of 5-feet and returned to the laboratory in sealed containers for further testing and evaluation. A detailed description of the field exploration program and the boring logs are presented in Appendix B.

LABORATORY TESTING PROGRAM

Selected soil samples obtained during the field investigation were subjected to laboratory testing to evaluate their physical and engineering properties. Laboratory testing included moisture content, dry density, compaction characteristics, and direct

shear tests. A detailed description of the laboratory testing program and the test results are presented in Appendix C.

SUBSURFACE CONDITIONS

Data from our exploratory borings indicate that the subsurface soil profile at the site generally consists of surficial silty sands underlain by well graded sands and additional silty sands. A strata of silty sand with clay was encountered within Boring No. 2. up to 2-feet of unengineered fill materials were present within Boring No. 2. Groundwater or bedrock was not encountered in any of our exploratory borings.

The subsurface conditions encountered in our exploratory borings are only indicative of the locations explored, and are not to be construed as representing the same conditions throughout the site. If conditions are encountered during the construction of the project which differ significantly from those presented in this report, this firm should be notified immediately so we may assess the impact to the recommendations provided.

A more detailed description of the subsurface soil conditions, as encountered within our exploratory borings, is presented on the Boring Logs within Appendix B.

CONCLUSIONS

On the basis of our field investigation and testing program, it is the opinion of LOR Geotechnical Group, Inc. that the proposed development is feasible from a soil engineering standpoint, provided the recommendations presented in this report are incorporated into design and implemented during grading and construction.

Based upon the field investigation and test data, it is our opinion that the upper native soils will not, in their present condition, provide uniform support for the proposed structures. Our Standard Penetration Test (SPT) and in-place density data indicated variable in-situ conditions of the upper native soils, ranging from medium dense to dense states. This condition may cause unacceptable differential and/or overall settlements upon application of the anticipated foundation loads.

To provide adequate support for the proposed structures, we recommend a compacted fill mat be constructed beneath the foundations. This compacted fill mat will provide a dense, high-strength soil layer to uniformly distribute the anticipated foundation loads over the underlying soils. In addition, the construction of this compacted fill mat will allow for the removal of any old fill material, and recompaction of existing upper disturbed soils within structural pad areas. Conventional spread foundations will provide adequate support for the anticipated downward and lateral loads when utilized in conjunction with the recommended fill mat.

The following recommendations are provided for your assistance in establishing proper design, grading and construction criteria.

RECOMMENDATIONS

General Site Grading

It is imperative that no clearing and/or grading operations be performed without the presence of a qualified geotechnical engineer. Prior to all grading related operations an on-site, pre-job meeting with UCR's representatives, the project engineer, the contractor and geotechnical engineer should occur. Operations undertaken at the site without the geotechnical engineer present may result in exclusion of affected areas from the final compaction report for the project.

Grading of the subject site should be performed in accordance with the following recommendations as well as applicable portions of Appendix Chapter 33 of the 1994 Uniform Building Code, and/or applicable local ordinances.

All areas to be graded should be stripped of significant vegetation and other deleterious materials.

All uncontrolled fills encountered during site preparation should be completely removed, cleaned of significant deleterious materials, and may be reused as compacted fill.

Cavities created by removal of subsurface obstructions should be thoroughly cleaned of loose soil, organic matter and other deleterious materials, shaped to provide access for construction equipment, and backfilled as recommended in the following Compacted Fills section of this report.

Preparation of Fill Areas

Prior to placing fill, the surfaces of all areas to receive fill should be scarified to a depth of at least 12-inches. The scarified soil should be brought to near optimum moisture content and recompactd to a relative compaction of at least 90 percent (ASTM D 1557).

Preparation of Foundation Areas

All footings and spread foundations should rest upon at least 12-inches of properly compacted fill material. In areas where the required thickness is not accomplished by site rough grading, the footing areas should be further subexcavated to a depth of at least 12-inches below the proposed foundation base grade, with the subexcavation extending at least 5-feet beyond the footing lines. The bottom of this excavation should then be scarified to a depth of at least 6-inches, brought to near optimum moisture content, and recompactd to at least 90 percent relative compaction (ASTM D 1557) prior to refilling the excavation to grade as properly compacted fill.

Engineered Compacted Fill

The on-site soils should provide adequate quality fill material, provided they are free from organic matter and other deleterious materials. Unless approved by the geotechnical engineer, rock or similar irreducible material with a maximum dimension greater than 6-inches should not be buried or placed in fills.

Import fill should be inorganic, non-expansive granular soils free from rocks or lumps greater than 6-inches in maximum dimension. Sources for import fill should be approved by the geotechnical engineer prior to their use.

Fill should be spread in maximum 8-inch loose lifts, each lift brought to near optimum moisture content, and compacted to a relative compaction of at least 90 percent in accordance with ASTM D 1557.

Based upon the average in-situ dry density of the near surface soils determined during this investigation and the relative compaction anticipated for compacted fill soil, we estimate a compaction shrinkage factor of approximately five to ten percent. Therefore, 1.05 cubic yard to 1.10 cubic yards of in-place material would yield 1.0 cubic yard of engineered compacted fill. We would anticipate subsidence to be negligible. These values are for estimating purposes only, and are exclusive of losses due to stripping or the removal of subsurface obstructions. These values may vary due to differing conditions within the project boundaries and the limitations of this investigation. Shrinkage or bulking should be monitored during construction. If percentages vary, provisions should be made to revise final grades or adjust quantities of borrow or export.

Short Term Excavations

Following the California Occupational and Safety Health Act (CALOSHA) requirements, excavations deeper than 5-feet should be sloped or shored. All excavations and shoring should conform to CAL-OSHA requirements. Short term excavations greater than 5-feet deep shall conform to Title 8 of the California Code of Regulations, Construction Safety Orders, Section 1504 and 1539 through 1547. Based on our exploratory borings it appears that type C soils are the predominant type of soil on the project and all short term excavations should be based on this type of soil. Deviation from the standard short term slopes are permitted using Option 4, Design by a Registered Professional Engineer (Section 1541.1). Short term slope construction and maintenance are the responsibility of the contractor, and should be a consideration of his methods of operation and the actual soil conditions encountered.

Soil Expansiveness

The upper materials encountered during this investigation were granular and considered to have a very low expansion potential. Therefore, specialized construction procedures to specifically resist expansive soil activity are not anticipated at this time.

In order to verify this, additional evaluation of on-site and imported soils for their expansion potential should be conducted following completion of the grading operation.

Foundation Design

If the site is prepared as recommended, the proposed structures may be safely founded on conventional spread foundations, bearing on a minimum of 12-inches of engineered compacted fill. All foundations should be a minimum of 12-inches wide and be established a minimum of 12-inches below lowest adjacent grade.

For the minimum width and depth, footings may be designed using a maximum soil bearing pressure of 2500 pounds per square foot (psf) for dead plus live loads. This bearing pressure may be increased by 500 psf for each foot of additional width, and by 500 psf for each additional foot of depth, up to a maximum of 6000 psf. For example, a footing 2-feet wide and embedded 2-feet will have an allowable bearing pressure of 3500 psf.

The values apply to the maximum edge pressure for foundations subjected to eccentric loads or overturning. The recommended pressures apply for the total of dead plus frequently applied live loads, and incorporate a factor of safety of at least 3.0. The allowable bearing pressures may be increased by one-third for temporary wind or seismic loading. The resultant of the combined vertical and lateral seismic loads should act within the middle one-third of the footing width. The maximum calculated edge pressure under the toe of foundations subjected to eccentric loads or overturning should not exceed the increased allowable pressure.

Resistance to lateral loads will be provided by passive earth pressure and base friction. For footings bearing against compacted fill, passive earth pressure may be considered to be developed at a rate of 350 pounds per square foot per foot of depth. Base friction may be computed at 0.40 times the normal load. Base friction and passive earth pressure may be combined without reduction. These values are for dead load plus live load and may be increased by 1/3 for wind or seismic.

Settlement

Total settlement of individual foundations will vary depending on the width of the foundation and the actual load supported. Maximum settlement of shallow foundations designed and constructed in accordance with the preceding recommendations are estimated to be on the order of 0.5 inch. Differential settlement between adjacent footings should be about one-half of the total settlement. Settlement of all foundations is expected to occur rapidly, primarily as a result of elastic compression of supporting soils as the loads are applied, and should be essentially completed shortly after initial application of the loads.

Slabs-On-Grade

To provide adequate support, concrete slabs-on-grade should bear on a minimum of 12-inches of compacted soil. The final pad surfaces should be rolled to provide smooth, dense surfaces upon which to place the concrete.

Slabs to receive moisture-sensitive coverings should be provided with a moisture vapor barrier. This barrier may consist of an impermeable membrane. Two inches of sand over the membrane will reduce punctures and aid in obtaining a satisfactory concrete cure. The sand should be moistened just prior to placing of concrete.

The slabs should be protected from rapid and excessive moisture loss which could result in slab curling. Careful attention should be given to slab curing procedures, as the site area is subject to large temperature extremes, humidity, and strong winds.

Wall Pressures

The design of footings for walls below grade (basement or pit walls, etc.) and retaining structures should be performed in accordance with the recommendations described earlier under Preparation of Foundation Areas and Foundation Design. For design of retaining wall footings, the resultant of the applied loads should act in the middle one-third of the footing, and the maximum edge pressure should not exceed the basic allowable value without increase.

For design of retaining walls unrestrained against movement at the top, we recommend an equivalent fluid pressure of 35 pounds per cubic foot (pcf) be used. This assumes level backfill consisting of recompacted native soils placed against the structures and with the backcut slope extending upward from the base of the stem at 30 degrees from the vertical or flatter.

To avoid overstressing or excessive tilting during placement of backfill behind walls, heavy compaction equipment should not be allowed within the zone delineated by a 45 degree line extending from the base of the wall to the fill surface. The backfill directly behind the walls should be compacted using light equipment such as hand operated vibrating plates and rollers. No material larger than three inches in diameter should be placed in direct contact with the wall.

Wall pressures should be verified prior to construction, when the actual backfill materials and conditions have been determined. Recommended pressures are applicable only to level, properly drained backfill (with no additional surcharge loadings). If inclined backfills are proposed, this firm should be contacted to develop appropriate active earth pressure parameters. Toe bearing pressure for non-structural walls on soils, not prepared as described earlier under Preparation of Foundation Areas, should not exceed Uniform Building Code values, (UBC Table 18-1-A).

Construction Monitoring

Post investigative services are an important and necessary continuation of this investigation. Project plans and specifications should be reviewed prior to construction to confirm that the intent of the recommendations presented herein have been incorporated into the design.

During construction, sufficient and timely geotechnical observation and testing should be provided to correlate the findings of this investigation with the actual subsurface conditions exposed during construction. Items requiring observation and testing include, but are not necessarily limited to, the following:

1. Site preparation-stripping and removals.
2. Excavations, including approval of the bottom of excavation prior to backfilling.
3. Scarifying and recompacting prior to fill placement.
4. Subgrade preparation for pavements and slabs-on-grade.
5. Placement of engineered compacted fill and backfill, including approval of fill materials and the performance of sufficient density tests to evaluate the degree of compaction being achieved.

LIMITATIONS

This report contains conclusions and recommendations of the subsurface soil conditions at the site developed solely for use by the owner, and their design consultants, for the purposes described earlier. It may not contain sufficient information for other uses or the purposes of other parties. This report did not address the geological conditions at the site nor their impact, if any, to the proposed development. The contents of this report should not be extrapolated to other areas or used for other facilities without consulting LOR Geotechnical Group, Inc.

The recommendations are based on interpretations of the subsurface conditions concluded from information gained from subsurface explorations, and a surficial site reconnaissance. The interpretations may differ from actual subsurface conditions, which can vary horizontally and vertically across the site. Due to possible subsurface variations, all aspects of field construction addressed in this report should be observed and tested by the project geotechnical consultant.

If parties other than LOR Geotechnical Group, Inc. provide construction monitoring services, they must be notified that they will be required to assume responsibility for the geotechnical phase of the project being completed by concurring with the recommendations provided in this report or by providing alternative recommendations.

Dagostino Engineering
February 12, 1996

Project No. 20742.1


The report was prepared using generally accepted geotechnical engineering practices under the direction of a state licensed geotechnical engineer. No warranty, express or implied, is made as to conclusions and professional advice included in this report. Any persons using this report for bidding or construction purposes should perform such independent investigations as deemed necessary to satisfy themselves as to the surface and subsurface conditions to be encountered and the procedures to be used in the performance of work on this project.

CLOSURE

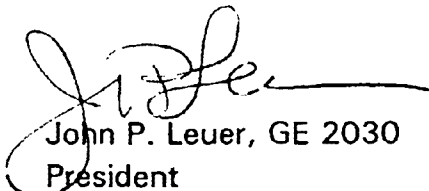
Should conditions be encountered during construction that appear to be different than indicated by this report, please contact this office immediately in order that we might evaluate their effect. It has been a pleasure to assist you with this project. We look forward to being of further assistance to you as construction begins.

Should you have any questions regarding this report, please contact us. The following are attached and complete this report:

Respectfully submitted,
LOR Geotechnical Group, Inc.



M. Kevin Osmun, PE
Vice President



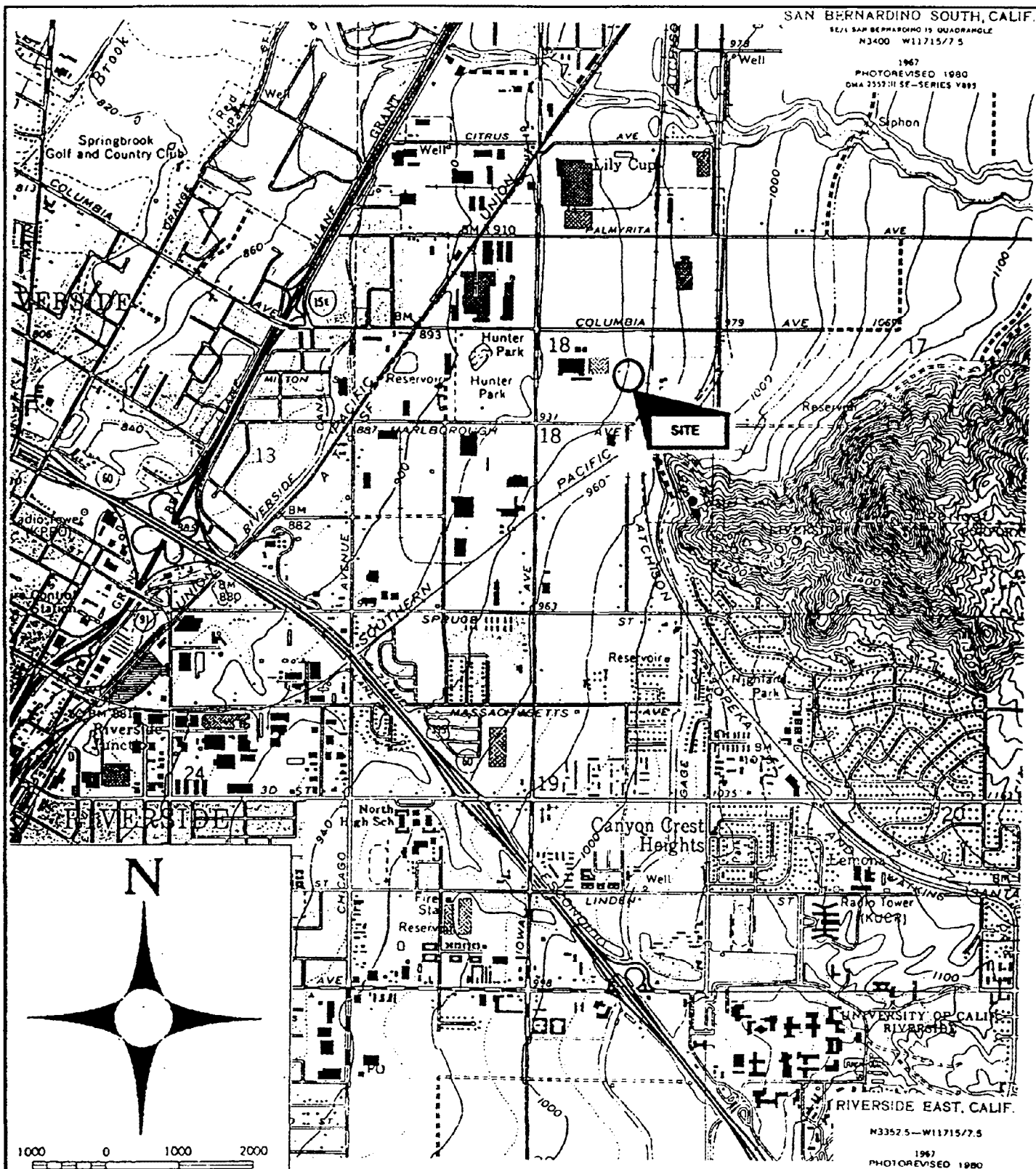
John P. Leuer, GE 2030
President



JLG:JPL:sju

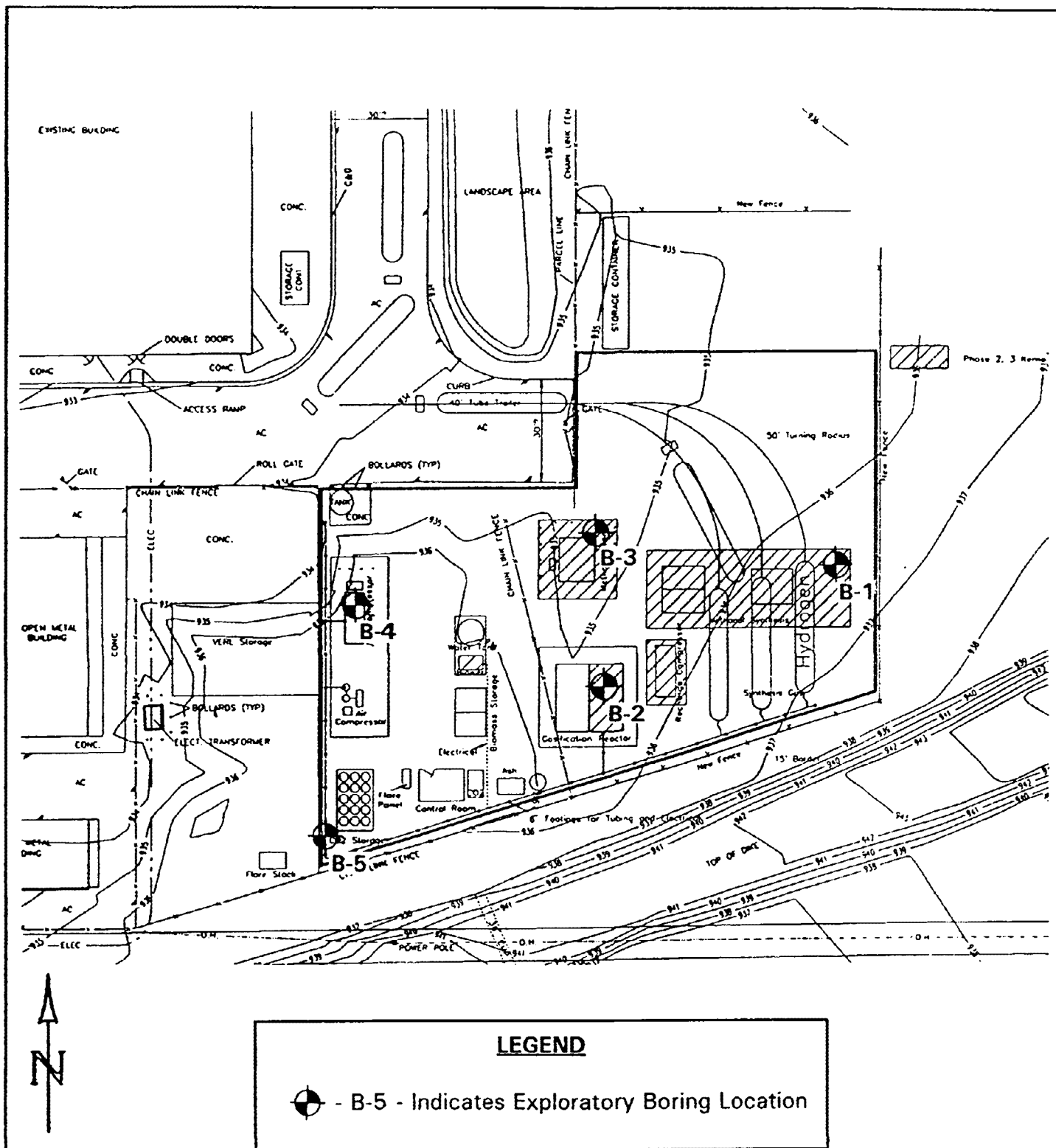
APPENDIX A

Index Map and Plat



INDEX MAP

| | | | |
|------------------------------|---|--------------|-------------------|
| PROJECT: | UCR, CE-CERT BIOMASS TO METHANOL FUEL PLANT | PROJECT NO.: | 20742.1 |
| CLIENT: | DAGOSTINO ENGINEERING | ENCLOSURE: | A-1 |
| LOR Geotechnical Group, Inc. | | DATE: | FEBRUARY 12, 1996 |
| | | SCALE: | AS SHOWN |



PLAT

| | | | |
|------------------------------|---|--------------|-------------------|
| PROJECT: | UCR, CE-CERT BIOMASS TO METHANOL FUEL PLANT | PROJECT NO.: | 20742.1 |
| CLIENT: | DAGOSTINO ENGINEERING | ENCLOSURE: | A-2 |
| LOR Geotechnical Group, Inc. | | DATE: | FEBRUARY 12, 1996 |
| | | SCALE: | NOT TO SCALE |

APPENDIX B

Field Investigation Program and Boring Logs

APPENDIX B FIELD INVESTIGATION

Subsurface Exploration

The site was investigated on February 1, 1996 and consisted of advancing five exploratory borings to depths between 23.5- and 30.0-feet below the existing ground surface. The approximate locations of the borings are shown on Enclosure A-2, within Appendix A.

The exploration was conducted using a CME-55 drill rig equipped with an 8-inch diameter hollow stem auger. The soils were continuously logged by our geologist who inspected the site, maintained detailed logs of the borings, obtained undisturbed, as well as disturbed, soil samples for evaluation and testing, and classified the soils by visual examination in accordance with the Unified Soil Classification System.

Relatively undisturbed samples of the subsoils were obtained at selected intervals in the borings by driving a steel split-barrel sampler using a 140 pound automatic trip hammer dropping 30-inches. The maximum depth between the samples obtained was 5-feet. The soil samples were retained in brass sample rings of 2.41-inches in diameter and 1.00-inch in height, and placed in sealed plastic containers. Disturbed soil samples were obtained at selected levels within the borings and placed in sealed plastic bags for transport to the laboratory.

All samples obtained were taken to our laboratory for storage and testing. Detailed logs of the borings are presented on the enclosed Boring Logs, Enclosures B-1 through B-5. A Sampling Key is presented on Enclosure B.

CONSISTENCY OF SOILS

SANDS

SPT BLOWS CONSISTENCY

| | |
|---------|--------------|
| 0 - 4 | Very loose |
| 4 - 10 | Loose |
| 10 - 30 | Medium dense |
| 30 - 50 | Dense |
| Over 50 | Very dense |

COHESIVE SOILS





SPT BLOWS CONSISTENCY














| | |
|---------|------------|
| 0 - 2 | Very soft |
| 2 - 4 | Soft |
| 4 - 8 | Medium |
| 8 - 15 | Stiff |
| 15 - 30 | Very stiff |
| 30 - 60 | Hard |
| Over 60 | Very Hard |

SYMBOL

SAMPLING KEY

DESCRIPTION

| | |
|---|--|
|  | FOR BORINGS — INDICATES RELATIVELY UNDISTURBED SOIL SAMPLE RETAINED IN BRASS SAMPLE RINGS OF 2.41 INCHES DIAMETER AND 1.00 INCH IN HEIGHT. |
|  | FOR TRENCHES — INDICATES SAND CONE OR NUCLEAR DENSITY TEST |
|  | INDICATES BAG SOIL SAMPLE |
|  | INDICATES BULK SOIL SAMPLE |

| MAJOR DIVISIONS | | | LITHO- LOGY | U.S. C.S. | TYPICAL DESCRIPTIONS | | |
|----------------------------|------------------------------------|---|---|---|---|--|---|
| COARSE GRAINED SOILS | GRAVEL AND GRAVELLY SOILS | CLEAN GRAVELS (LITTLE OR NO FINES) |  | GW | WELL-GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES | | |
| | | MORE THAN 50% OF COARSE FRACTION RETAINED ON NO. 4 SIEVE |  | GP | POORLY-GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES | | |
| | | | GRAVELS WITH FINES (APPRECIABLE AMOUNT OF FINES) |  | GM | SILTY GRAVELS, GRAVEL-SAND- SILT MIXTURES | |
| | | GC | CLAYEY GRAVELS, GRAVEL- SAND-CLAY MIXTURES | | | | |
| | SAND AND SANDY SOILS | CLEAN SAND (LITTLE OR NO FINES) |  | SW | WELL-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES | | |
| | | MORE THAN 50% OF COARSE FRACTION PASSING NO. 4 SIEVE |  | SP | POORLY-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES | | |
| | | | SANDS WITH FINES (APPRECIABLE AMOUNT OF FINES) |  | SM | SILTY SAND, SAND-SILT MIXTURES | |
| | | SC | CLAYEY SANDS, SAND-CLAY MIXTURES | | | | |
| FINE GRAINED SOILS | SILTS AND CLAYS | LIQUID LIMIT LESS THAN 50 |  | ML | INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY | | |
| | | |  | CL | INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS | | |
| | | |  | OL | ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY | | |
| | SILTS AND CLAYS | LIQUID LIMIT GREATER THAN 50 |  | MH | INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SAND OR SILTY SOILS | | |
| | | |  | CH | INORGANIC CLAYS OF RICH PLASTICITY, FAT CLAYS | | |
| | | |  | OH | ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS | | |
| | | | HIGHLY ORGANIC SOILS | |  | PT | PEAT, HUMUS, SWAMP SOILS WITH HIGH ORGANIC CONTENTS |

NOTE: DUAL SYMBOLS ARE USED TO INDICATE BORDERLINE SOIL CLASSIFICATIONS.

PARTICLE SIZE LIMITS

| BOULDERS | COBBLES | GRAVEL | | SAND | | | SILT OR CLAY |
|----------|---------|--------|-------|--------|--------|------|--------------|
| | | COARSE | FINE | COARSE | MEDIUM | FINE | |
| 12" | 3" | 3/4" | No. 4 | No. 10 | No. 40 | 200 | |

(U.S. STANDARD SIEVE SIZE)

UNIFIED SOIL CLASSIFICATION SYSTEM

| | | | |
|--------------------------------|-------------------------|--------------|----------------|
| PROJECT: | UCR, CE-CERT FUEL PLANT | PROJECT NO.: | 20742.1 |
| CLIENT: | DAGOSTINO ENGINEERING | DATE: | FEBRUARY, 1996 |
| LOR GEOTECHNICAL GROUP, | | CLOSURE NO.: | B |

| TEST DATA | | | | | | | | LOG OF BORING 1 | |
|---------------|--------------------------|--|-------------------------|----------------------|-------------|-----------|---------|--|--|
| DEPTH IN FEET | SPT BLOW COUNTS N(60) | | MOISTURE CONTENT (%) | DRY DENSITY (PCF) | SAMPLE TYPE | LITHOLOGY | U.S.C.S | DESCRIPTION | |
| 0 | | | 5.1 | | | | SM | OLDER ALLUVIUM: SILTY SAND; approximately 60% fine sand; 10% medium sand; 30% silty fines of low plasticity, strong brown (7.5YR 5/8), damp. | |
| 5 | 58 | | 13.6 | 116 | | | | Formation of pod-like soil structure with caliche cemented stringers, very dense. | |
| 10 | 70 | | 9.0 | 119 | | | | Several small clasts of almost completely weathered granitic gravel. | |
| 15 | 66 | | 11.3 | 123 | | | | | |
| 20 | 78 | | 7.2 | 129 | | | | | |
| 25 | 83 | | 6.0 | 121 | | | | Gradual decrease in silt content. Grades to approximately 60% fine grained sand; 20% medium grained sand; 5% coarse grained sand; 15% silty fines; yellowish red (5YR 5/8), damp. | |
| 30 | | | | | | | | End of Boring No Fill No Caving No Groundwater No Bedrock | |

| | | | |
|-------------------------------|-------------------------|-----------------------------------|------------------|
| PROJECT: | UCR, CE-CERT Fuel Plant | PROJECT NUMBER: | 20742.1 |
| CLIENT: | Dagostino Engineering | ELEVATION: | 936.5 |
| LOR GEOTECHNICAL GROUP | | DATE DRILLED: | February 1, 1996 |
| | | EQUIPMENT: | CME 55 Drill Rig |
| | | HOLE DIA.: 8" ENCLOSURE: B-1 | |

LOG OF BORING 2

| DEPTH IN FEET | TEST DATA | | | | | LITHOLOGY | U.S.C.S | DESCRIPTION |
|---------------|--------------------------|--|-------------------------|----------------------|-------------|-----------|---------|--|
| | SPT BLOW COUNTS N(60) | | MOISTURE CONTENT (%) | DRY DENSITY (PCF) | SAMPLE TYPE | | | |
| 0 | | | 4.3 | | | | SM | OLDER ALLUVIUM: SILTY SAND; approximately 70% fine grained sand; 5% medium grained sand; 25% silty fines of low plasticity; brownish yellow (10YR 6/8), dry. |
| 42-6" | | | 3.3 | 112 | | | | Grades to approximately 80% fine grained sand; 20% silty fines; light olive brown (2.5Y 5/4), dry, dense with caliche pods and stringers |
| 5 | | | | | | | | |
| 75 | | | 10.8 | 126 | | | SM | SILTY SAND/CLAYEY SAND: approximately 60% fine grained sand; 40% silty fines of medium plasticity; yellowish red (5YR 4/6) damp, dense/hard with caliche stringers. |
| 10 | | | | | | | | |
| 42-6" | | | 7.8 | 114 | | | SW | WELL GRADED SAND: with SILT; approximately 50% medium grained sand; 30% fine grained sand; 10% coarse sand, 10% silty fines, strong brown (7.5YR 5/8), damp. |
| 15 | | | | | | | | |
| 68 | | | 13.2 | 123 | | | SM | SILTY SAND: approximately 70% fine grained sand; 5% medium sand; 25% silty fines; strong brown (7.5YR 5/6), damp. |
| 20 | | | | | | | | |
| 77 | | | 8.5 | 129 | | | | |
| 25 | | | | | | | | |
| 38 | | | 9.7 | 124 | | | | Less SILTY, approximately 50% fine grained sand; 35% medium sand; 15% silty fines, strong brown (7.5YR 4/6), damp. |
| 30 | | | | | | | | END OF BORING No fill No caving No groundwater No bedrock |

| | | | |
|-------------------------------|-------------------------|-----------------|------------------|
| PROJECT: | UCR, CE-CERT Fuel Plant | PROJECT NUMBER: | 20742.1 |
| CLIENT: | Dagostino Engineering | ELEVATION: | 935.5 |
| LOR GEOTECHNICAL GROUP | | DATE DRILLED: | February 1, 1996 |
| | | EQUIPMENT: | CME 55 Drill Rig |
| | | OLE DIA.: 8" | ENCLOSURE: B-2 |

LOG OF BORING 3

| DEPTH IN FEET | TEST DATA | | | | | LITHOLOGY | U.S.C.S | DESCRIPTION |
|---------------|--------------------------|--|-------------------------|----------------------|-------------|-----------|---------|--|
| | SPT BLOW COUNTS N(60) | | MOISTURE CONTENT (%) | DRY DENSITY (PCF) | SAMPLE TYPE | | | |
| 0 | | | 6.2 | | Σ | | SM | OLDER ALLUVIUM: SILTY SAND; approximately 75% fine grained sand; 25% silty fines; brownish yellow (10YR 6/6), dry, loose. |
| 5 | 39-6" | | 5.3 | 121 | █ | | | Dense. |
| 10 | 51 | | 7.7 | 126 | █ | | | Strong brown (7.5YR 4/6), some caliche stringers. |
| 15 | 71 | | 6.5 | 126 | █ | | SW | WELL GRADED SAND: with SILT; approximately 50% fine grained sand; 20% medium sand; 20% coarse grained sand; 10% silty fines; strong brown (7.5YR 5/6), difficult to drill. |
| 20 | 63 | | 10.3 | 126 | █ | | SM | SILTY SAND: approximately 50% fine grained sand; 30% medium sand; 20% silty fines, trace of lean clay, yellowish brown (10YR 5/6), damp. |
| 25 | 73 | | 10.0 | 126 | █ | | | Water added @ 25.0' to facilitate drilling. |
| 30 | 45 | | 9.5 | 123 | █ | | | END OF BORING No fill No caving No groundwater No bedrock |

| | | | |
|-------------------------------|-------------------------|-----------------|------------------|
| PROJECT: | UCR, CE-CERT Fuel Plant | PROJECT NUMBER: | 20742.1 |
| CLIENT: | Dagostino Engineering | ELEVATION: | 934.5 |
| LOR GEOTECHNICAL GROUP | | DATE DRILLED: | February 1, 1996 |
| | | EQUIPMENT: | CME 55 Drill Rig |
| | | BOLE DIA.: 8" | ENCLOSURE: B-3 |

| TEST DATA | | | | | | | | LOG OF BORING 4 |
|---------------|--------------------------|--|-------------------------|----------------------|-------------|-----------|---------|--|
| DEPTH IN FEET | SPT BLOW COUNTS N(60) | | MOISTURE CONTENT (%) | DRY DENSITY (PCF) | SAMPLE TYPE | LITHOLOGY | U.S.C.S | |
| 0 | | | 11.5 | | | | SM | DESCRIPTION |
| 20 | | | 7.3 | 126 | | | SM | FILL: SILTY SAND; approximately 70% fine grained sand; 30% silty fines, brown (7.5YR 4/3), moist. |
| 5 | | | | | | | | OLDER ALLUVIUM: SILTY SAND; approximately 65% fine grained sand; 5% medium sand; 30% silty fines; strong brown (7.5YR 4/6), moist. |
| 28 | | | 3.2 | 118 | | | SW | WELL GRADED SAND; with SILT; approximately 60% fine grained sand; 20% medium grained sand; 10% coarse sand; 10% silty fines; strong brown (7.5YR 5/8), damp. |
| 10 | | | | | | | | |
| 76 | | | 7.4 | 122 | | | | |
| 15 | | | | | | | | Difficult drilling, water added to facilitate drilling effort. |
| 78 | | | 12.9 | 119 | | | SM | SILTY SAND: approximately 60% fine grained sand; 10% medium sand; 30% silty fines; yellowish brown (10YR 5/8), damp. |
| 20 | | | | | | | | |
| 88 | | | 9.4 | 126 | | | | |
| 25 | | | | | | | | END OF BORING Fill 0-1.0' No caving No groundwater No bedrock |
| 30 | | | | | | | | |

| | | | |
|--------------------------|-------------------------|-----------------|------------------|
| PROJECT: | UCR, CE-CERT Fuel Plant | PROJECT NUMBER: | 20742.1 |
| CLIENT: | Dagostino Engineering | ELEVATION: | 936.0 |
| | | DATE DRILLED: | February 1, 1996 |
| LOR GEOTECHNICAL GROUP I | | EQUIPMENT: | CME 55 Drill Rig |
| | | LE DIA.: 8" | ENCLOSURE: B-4 |

LOG OF BORING 5

| TEST DATA | | | | | | |
|---------------|--------------------------|--|-------------------------|----------------------|-------------|-----------|
| DEPTH IN FEET | SPT BLOW COUNTS N(60) | | MOISTURE CONTENT (%) | DRY DENSITY (PCF) | SAMPLE TYPE | LITHOLOGY |
| 0 | | | 5.8 | | | |
| 5 | 41 | | 2.1 | 108 | | |
| 10 | 67 | | 10.6 | 126 | | |
| 15 | 76 | | 9.9 | 125 | | |
| 20 | 49 | | 4.3 | 116 | | |
| 25 | 37 | | 7.8 | 125 | | |
| 30 | | | | | | |

DESCRIPTION

OLDER ALLUVIUM: SILTY SAND; approximately 70% fine grained sand; 10% medium; 20% silty fines; dark yellowish brown (10YR 4/6), damp.

SILTY SAND; with lenses of coarse grained granitic sand, some caliche stringers, dense.

Fewer lenses of coarse sand.

Difficult to drill, water added to facilitate drilling effort.

WELL GRADED SAND: approximately 30% fine grained sand; 40% medium sand; 30% coarse sand; brownish yellow (10YR 6/6), damp.

SILTY SAND: percentages vary, approximately 60% fine sand; 10% medium sand; 30% silty fines; dark reddish brown (5YR 3/4), damp.

END OF BORING

No fill
No caving
No groundwater
No bedrock

PROJECT: UCR, CE-CERT Fuel Plant

CLIENT: Dagostino Engineering

PROJECT NUMBER: 20742.1

ELEVATION: 936.0

DATE DRILLED: February 1, 1996

EQUIPMENT: CME 55 Drill Rig

LE DIA.: 8" ENCLOSURE: B-5

LOR GEOTECHNICAL GROUP

APPENDIX C

Laboratory Testing

APPENDIX C LABORATORY TESTING

General

Selected soil samples obtained from the borings were tested in our laboratory to evaluate the physical properties of the soils affecting foundation design and construction procedures. The laboratory testing program performed in conjunction with our investigation included moisture content, dry density, compaction characteristics, and direct shear tests. Descriptions of the laboratory tests are presented in the following paragraphs.

Moisture-Density Tests

The moisture content and dry density information provides an indirect measure of soil consistency for each stratum, and can also provide a correlation between soils on this site. The dry unit weight and field moisture content were determined for selected undisturbed samples, and the results are shown on the boring logs, Enclosures B-1 through B-5, for convenient correlation with the soil profile.

Direct Shear Test

Shear tests are performed with a direct shear machine at a constant rate-of-strain (usually 0.05 inches/minute). The machine is designed to test a sample partially extruded from a sample ring in single shear. The sample was tested at varying normal loads in order to evaluate the shear strength parameters, angle of internal friction and cohesion. The sample was tested in undisturbed condition at field moisture content or soaked, according to conditions existing in the field.

The results of the shear test is presented in the following table.

| Shear Test Results | | | | |
|--------------------|---------------------|------------------|--------------------------------------|----------------|
| Boring No. | Sample Depth (feet) | Soil Description | Angle of Internal Friction (degrees) | Cohesion (psf) |
| 2 | 2.0 | Silty Sand | 38 | 100 |

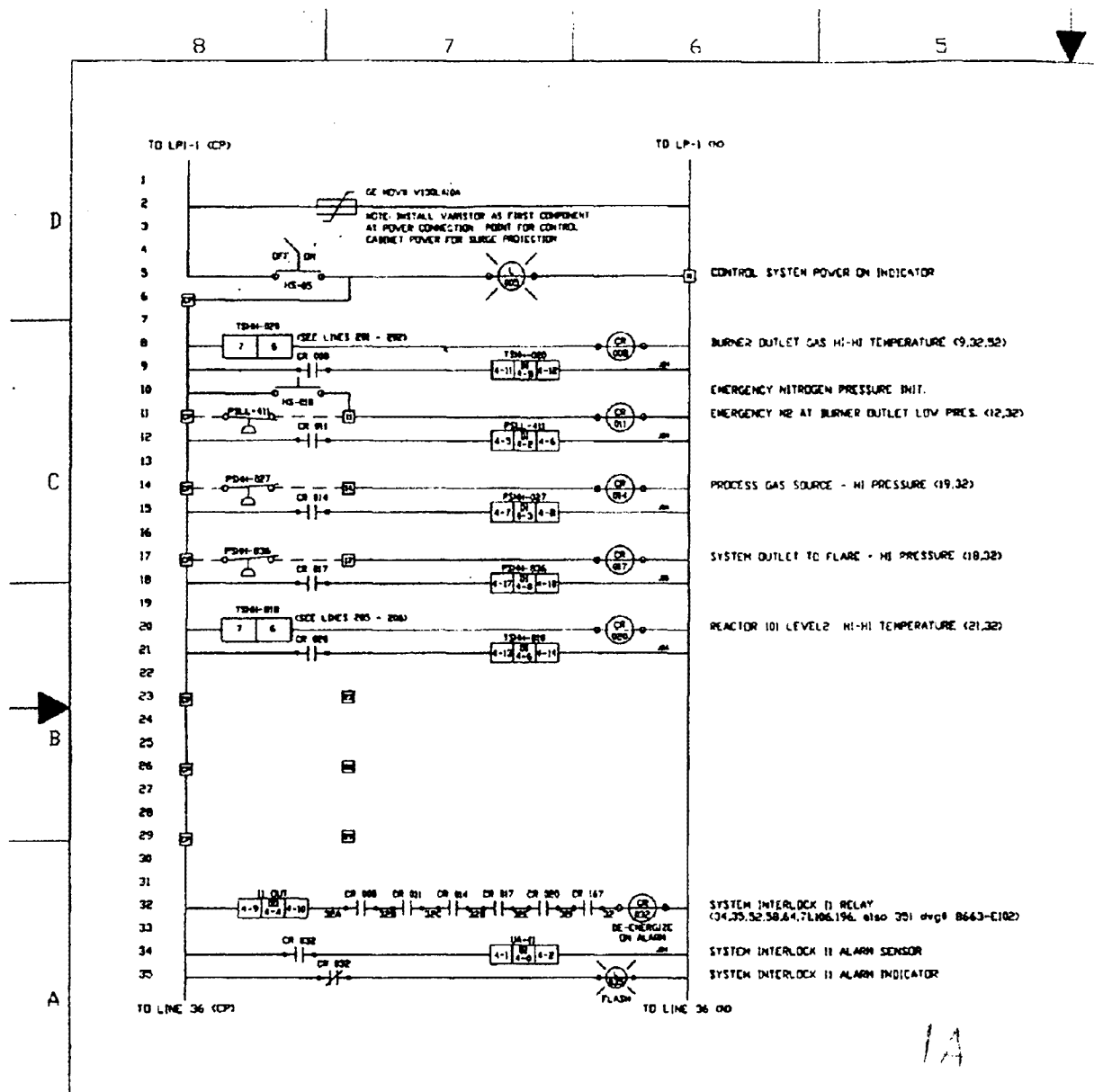
Compaction Characteristics

Selected soil samples were tested in the laboratory to determine compaction characteristics using the ASTM D 1557 compaction test method. The results are presented in the following table:

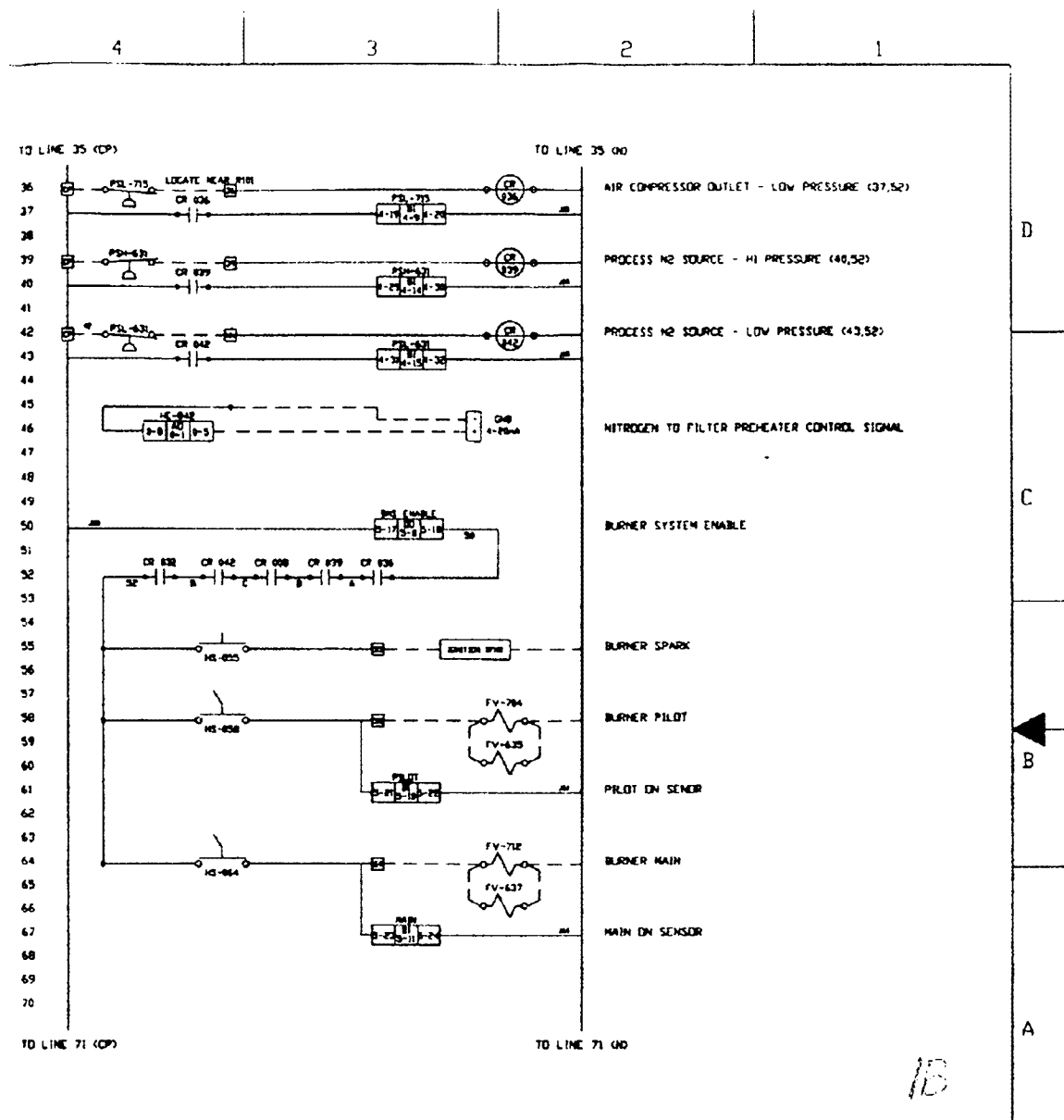
| LABORATORY COMPACTION | | | | |
|-----------------------|---------------------|------------------|---------------------------|------------------------------------|
| Boring Number | Sample Depth (feet) | Soil Description | Maximum Dry Density (pcf) | Optimum Moisture Content (percent) |
| 1 | 6.0 | Silty Sand | 123.5 | 11.5 |
| 4 | 10.0 | Sand | 133.5 | 7.5 |

Appendix III

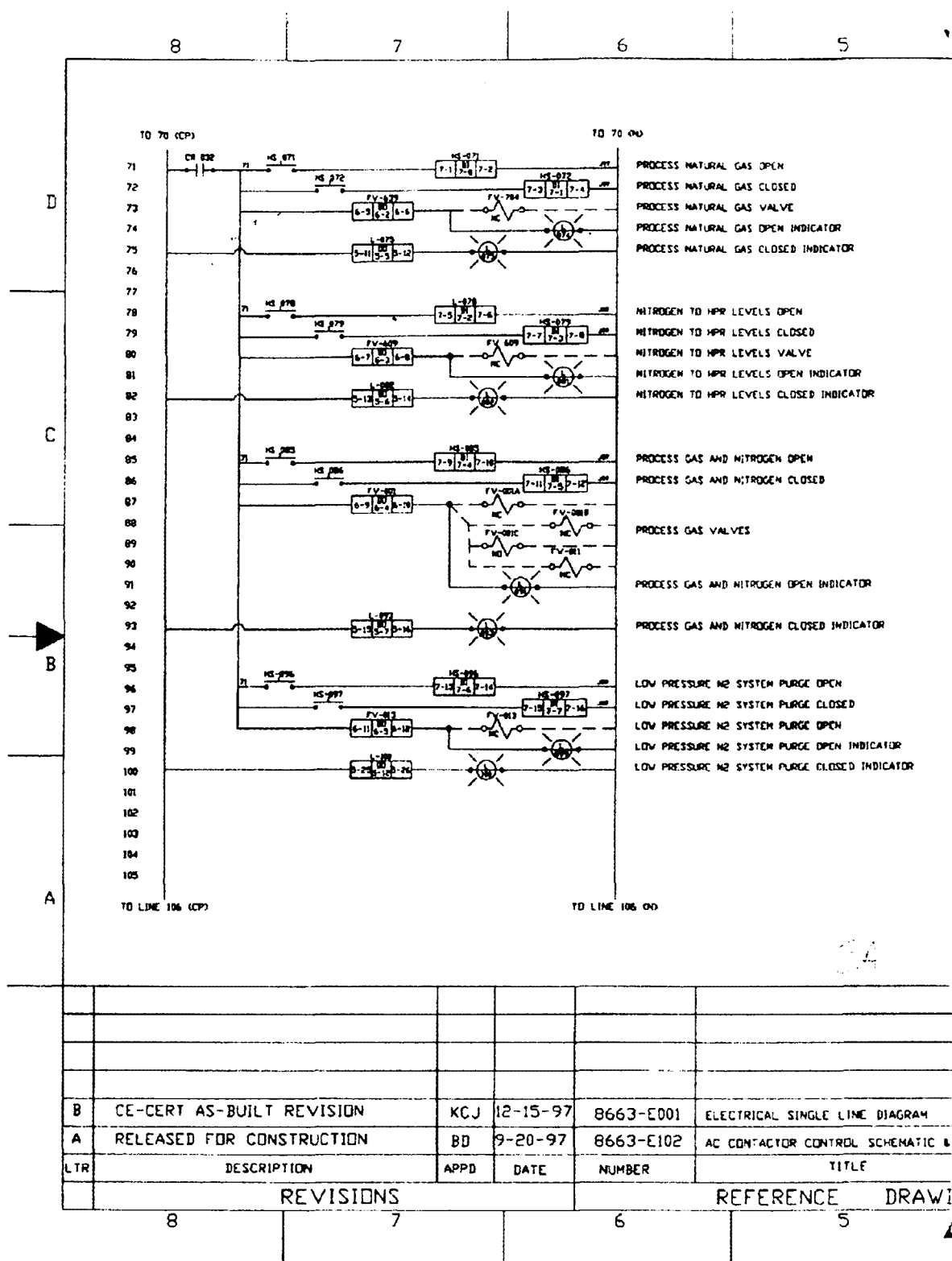
Hynol Facility Control Panel

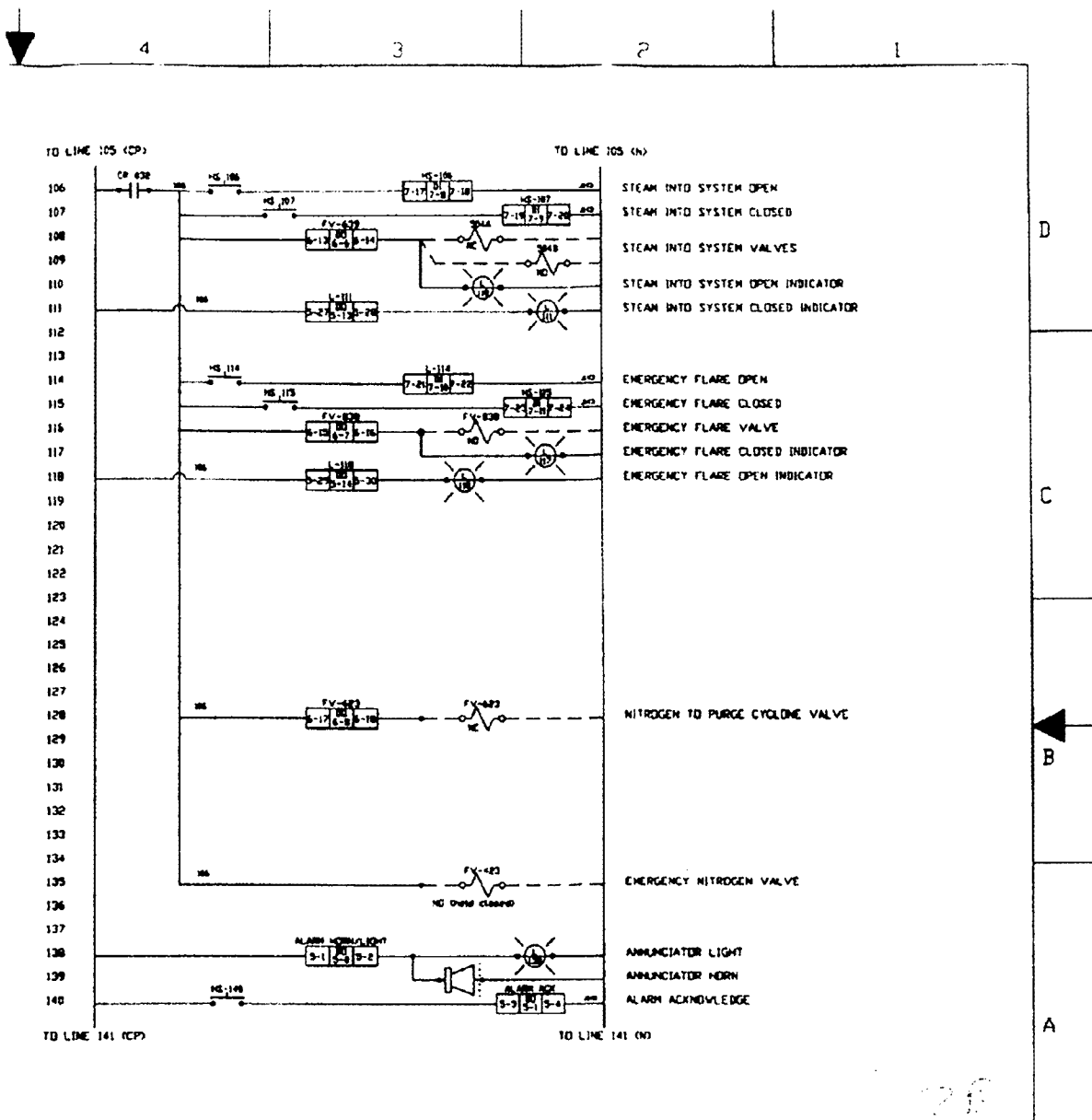


| | | | | | |
|-----|---------------------------|------|----------|-----------|-------------------------------------|
| | | | | | |
| | | | | | |
| | | | | | |
| B | CE-CERT AS-BUILT REVISION | KCJ | 12-15-97 | 8663-E001 | ELECTRICAL SINGLE LINE DIAGRAM |
| A | RELEASED FOR CONSTRUCTION | BD | 04-20-97 | 8663-E102 | AC CONTACTOR CONTROL SCHEMATIC & W: |
| LTR | DESCRIPTION | APPD | DATE | NUMBER | TITLE |
| | REVISIONS | | | REFERENCE | DRAWING |
| | 8 | 7 | 6 | 5 | |

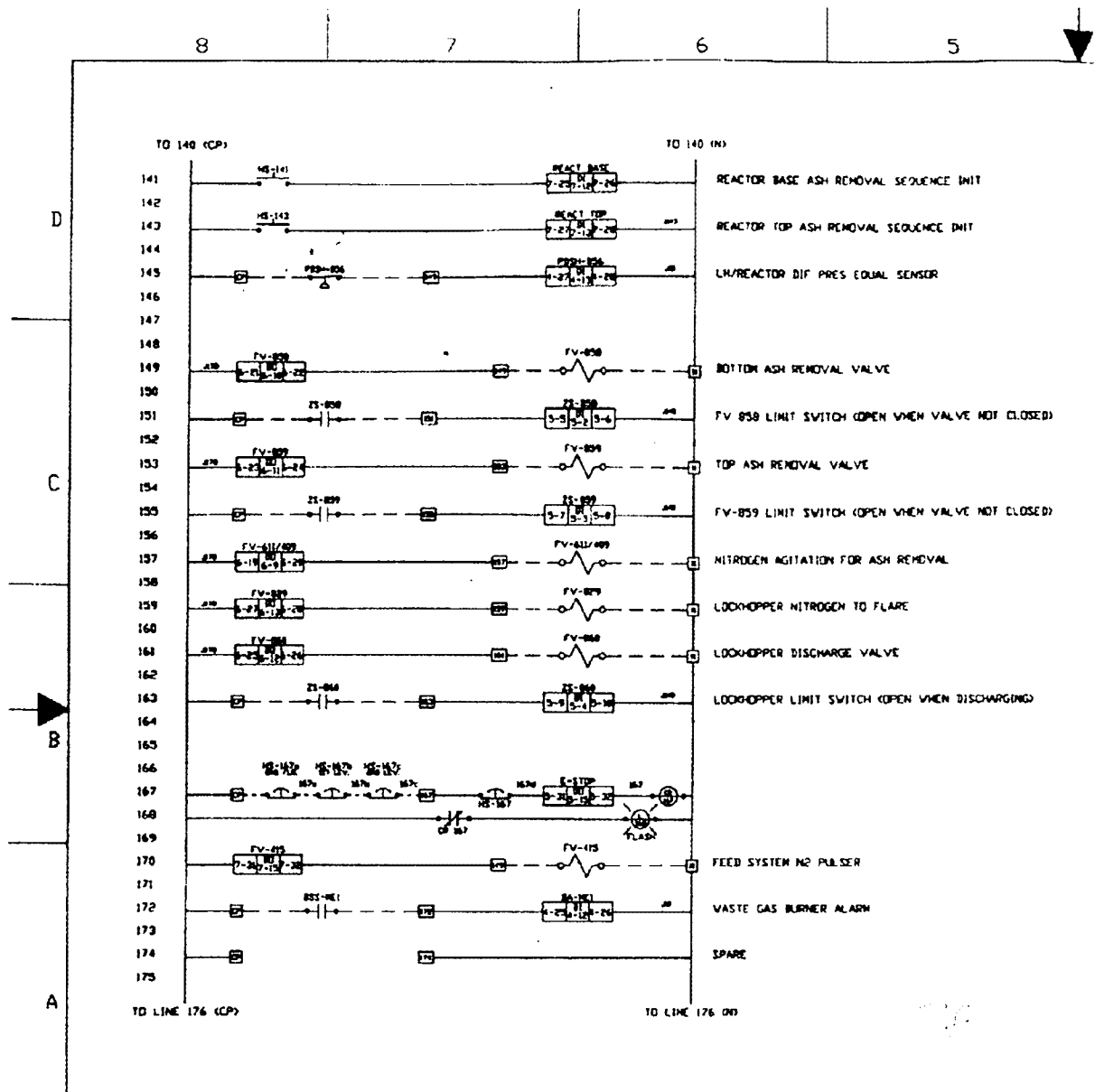


| | | | | | | |
|--------------------|----------|----------|----------------------------------|--------|-----|--|
| DWN | B. Doss | 09-20-97 | Acurex Environmental Corporation | | | |
| CHK | | | PROJECT | | | |
| ENG | | | H Y N O L | | | |
| APPD | | | HPR CONTROL PANEL CP-1 | | | |
| PROJECT NO. | 8663 | | SCHEMATIC AND WIRING DIAGRAM | | | |
| SCALE | NONE | | | | | |
| ORIGINATING OFFICE | CAGE NO. | SIZE | DWG. NO. | SHEET | REV | |
| Mountain View, CA | 08C85 | B | 8663-E101 | 1 of 4 | B | |
| Durham, NC | 083V1 | | | | | |
| Jefferson, AR | 083V4 | | | | | |

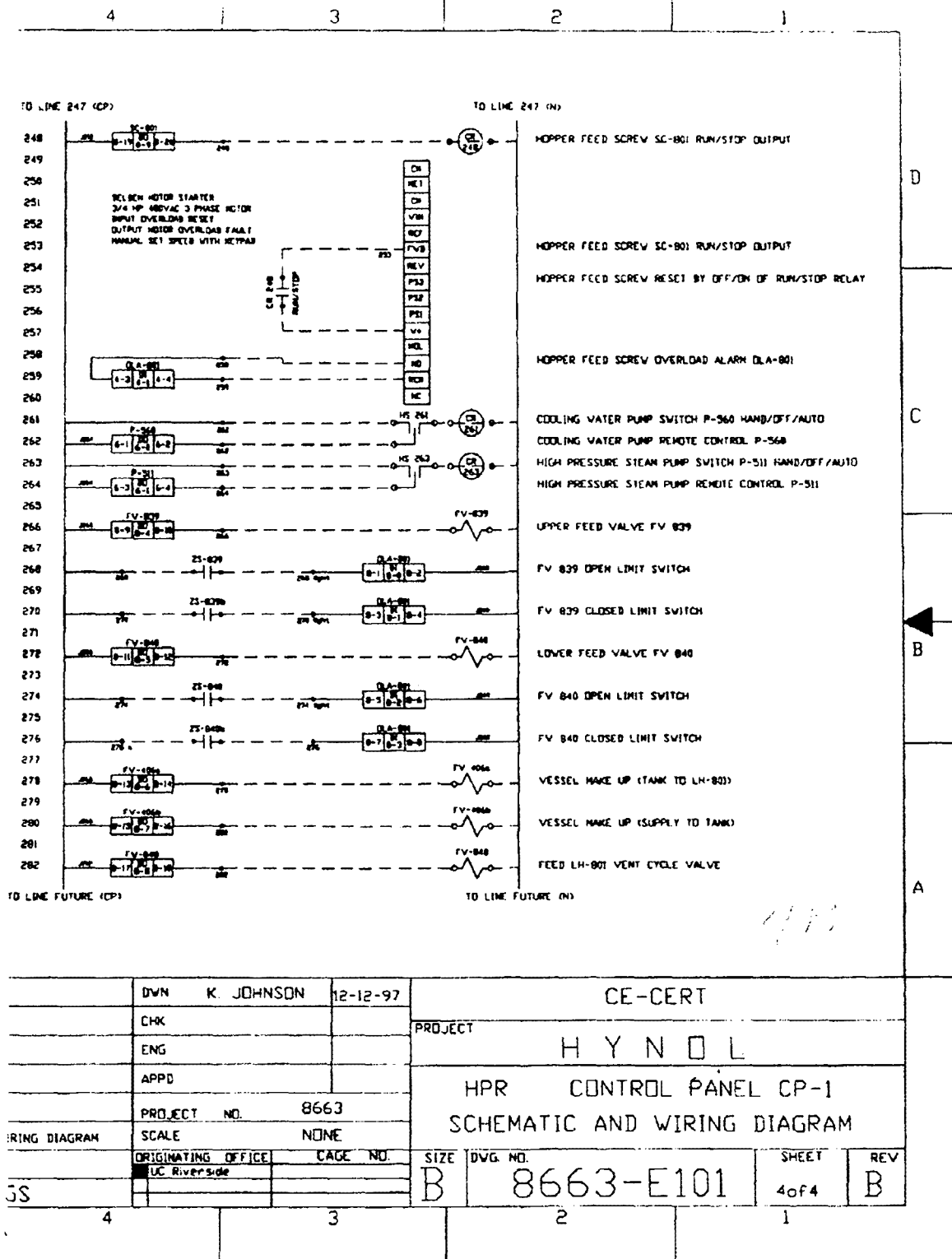




| | | | | | | |
|--------------------|----------|----------|------------------------------|--------|-----|--|
| DWN | B. DOSS | 12-31-95 | Acurex Environmental | | | |
| CHK | | | PROJECT | | | |
| ENG | | | H Y N O L | | | |
| APPD | | | HPR CONTROL PANEL CP-1 | | | |
| PROJECT NO. | 8663 | | SCHEMATIC AND WIRING DIAGRAM | | | |
| WIRING DIAGRAM | SCALE | NONE | | | | |
| ORIGINATING OFFICE | CAGE NO. | SIZE | DWG. NO. | SHEET | REV | |
| UC Riverside | | B | 8663-E101 | 2 of 4 | B | |



| | | | | | |
|-----|---------------------------|------|----------|-------------------|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| B | CE-CERT AS-BUILT REVISION | KCJ | 12-15-97 | 8663-E001 | ELECTRICAL SINGLE LINE DIAGRAM |
| A | RELEASED FOR CONSTRUCTION | BD | 9-20-97 | 8663-E102 | AC CONTACTOR CONTROL SCHEMATIC & WIRING |
| LTR | DESCRIPTION | APPD | DATE | NUMBER | TITLE |
| | REVISIONS | | | REFERENCE DRAWING | |
| | 8 | 7 | 6 | 5 | |



EVALUATION OF A PROCESS TO CONVERT BIOMASS TO METHANOL FUEL

PHASE I Project Category III

Quality Assurance Project Plan

December 1995

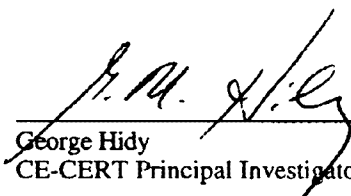
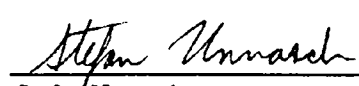
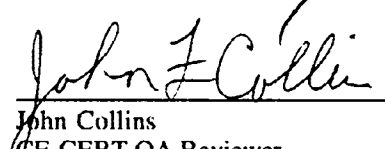

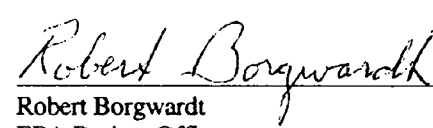
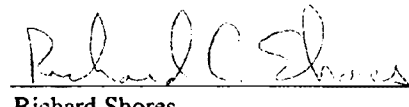
Prepared for
The U. S. Environmental Protection Agency
Air and Energy Engineering Laboratory
Research Triangle Park, NC 27711
Under Cooperative Agreement No. CR-824-308-1010

by

The Bourns College of Engineering
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| | | | |
|--|------------------------|--|------------------------|
|  George Hidy CE-CERT Principal Investigator | <u>12/1/95</u> Date |  Stefan Unnasch Acurex Environmental Project Manager | <u>12/8/95</u> Date |
|  John Collins CE-CERT QA Reviewer | <u>12/4/95</u> Date |  Libby Beach Acurex Environmental QA Reviewer | <u>2-1-96</u> Date |
|  Robert Borgwardt EPA Project Officer | <u>1/11/96</u> Date |  Richard Shores EPA QA Manager | <u>1-31-96</u> Date |

EVALUATION OF A PROCESS TO CONVERT BIOMASS TO METHANOL FUEL

PHASE I Project Category III

Quality Assurance Project Plan

December 1995

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|----------------|---|--------------|-----------------|----------------------|
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| 2 | PROJECT ORGANIZATION AND RESPONSIBILITIES | 2 | 1 | December 1995 |
| 3 | DATA QUALITY INDICATOR GOALS FOR CRITICAL HPR MEASUREMENTS | 1 | 1 | December 1995 |
| 4 | SAMPLING PROCEDURES FOR THE HPR | 14 | 1 | December 1995 |
| 5 | ANALYTICAL PROCEDURES FOR THE HPR | 3 | 1 | December 1995 |
| 6 | HPR DATA REDUCTION, VALIDATION, AND, REPORTING | 7 | 1 | December 1995 |
| 7 | ERROR ANALYSIS FOR THE HPR | 6 | 1 | December 1995 |
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| 9 | CORRECTIVE ACTION | 1 | 1 | December 1995 |

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SECTION 1

PROJECT DESCRIPTION AND DATA QUALITY OBJECTIVES

1.1 OVERALL PROJECT DESCRIPTION

The overall objective of this project is to demonstrate the technical feasibility of producing methanol from biomass using the Hynol process. The objective of the first component of the project is to build, install, and test the biomass hydrogasification system to be used in the Hynol process. A pilot plant has been designed to convert 50 lb/hr of biomass to methanol. The biomass may consist of wood and/or greenwaste, with natural gas as a co-feedstock. Sewage sludge and digester gas or landfill gas may also be used as secondary feedstocks. If its performance is verified, the process offers advantages in carbon conversion and energy efficiency as well as environmental protection. Compared with other methanol production processes, direct emissions of CO_2 can be substantially reduced using the Hynol process.

There are three steps to methanol production using the Hynol process:

1. Biomass and methane are introduced into a hydrogen pyrolysis reactor (HPR) in the presence of hydrogen. The HPR produces primarily methane, hydrogen, and water.
2. The methane gas mixture is then converted with steam and added natural gas to hydrogen and carbon monoxide in the steam pyrolyzer (SPR).
3. The output from the SPR is then cooled and introduced to the methanol synthesis reactor (MSR), which produces the methanol. The unreacted hydrogen and methane are recirculated from the MSR back into the HPR.

Figure 1-1 illustrates the three principal reactors in the Hynol process.

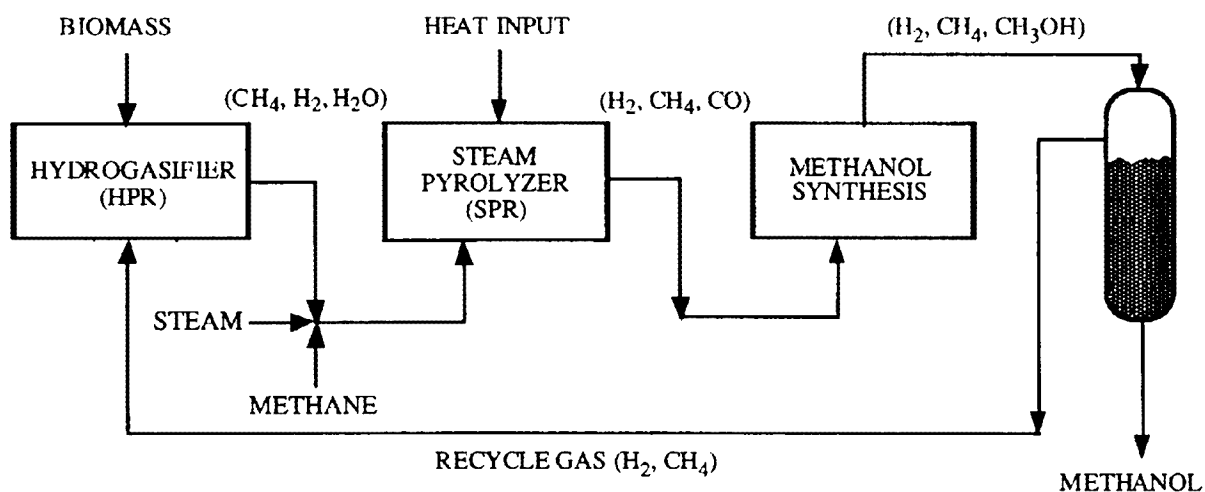


Figure 1-1. Hynol process block diagram

This component of the demonstration will provide for HPR construction, process, and operating data for use in the construction of a large-scale plant.

The project has been divided into three phases:

- Phase I—Fabrication, installation, and initial testing of the HPR
- Phase II—Design, construction, installation and testing of the SPR and MSR
- Phase III—Integration of the system to test and demonstrate the Hynol process

This plan concerns only the HPR testing in Phase I.

In preparation for Phase I, the initial conceptual design of the HPR and the methanol facility has been accomplished to achieve a cost estimate, and to complete detailed design specifications of the HPR unit. The design parameters have been evaluated to accommodate the specific biomass feedstocks available for the pilot plant.

The conceptual design has included a specification of all of the process flows for each of the units specific to the biomass feedstock. The design includes a detailed process and instrumentation diagram (P&ID) for the principal components of the process. At this point, basic design efforts for the hardware are complete, including detailed design drawings for the HPR system. The detailed design includes site-specific drawings for the installation of the equipment, revised design drawings, and vendor quotes on all equipment.

Phase I now involves construction, assembly, and checkout of the hydrogasifier design. In this phase, construction specifications will be prepared. The equipment from the design will be procured, including the HPR, the biomass feed system, the lock hopper, and the gas compressors. The facility will be assembled at the pilot-plant site in Riverside, California. It is expected that the HPR unit will be constructed on a skid and mounted on a concrete pad at the site. Preliminary operating data will be gathered so that the SPR and MSR designs can be completed later. Data on HPR performance will include carbon conversion efficiency, energy utilization reactor bottoms, and gas compositions as a function of feedstock type, feed rates, temperature and pressure. Table 1-1 shows the type of data to be collected during HPR operation.

This report addresses the quality assurance (QA) plans for the HPR operation based on an EPA Category III QA Protocol.

1.2 DATA QUALITY OBJECTIVES FOR PHASE I: HPR

The purpose of this study is to demonstrate the feasibility of hydrolyzing biomass feedstocks at high pressure and temperature in the presence of varying simulated recycle gases. The study will determine an optimal initial feedstock that minimizes potential problems associated with feedstock impurities and maximizes conversion to methane, H₂, and H₂O. The overall goal of the project is to achieve at least 80-percent carbon conversion efficiency at a feed flow rate of 50 lb/hr. The study will also determine the optimal ranges of feedstock flow rate, fluidized bed height, and operating parameters such as pressure drop, temperature, and heat loss in the prototype HPR.

To meet these objectives, a comprehensive sampling and analysis matrix will be developed specifying the flow rates of the reactor inlet gases and the solids feed rates for varying feedstock compositions. The bench-scale HPR will be constructed, installed, and tested using various combinations of feedstock compositions and flow rates in a range of pressure and temperature. The data quality must be ensured so that a range of operating parameters can be determined that yields a carbon conversion within an acceptable range of the goal of 80 percent or greater.

1.2.1 Critical and Noncritical Parameters

Critical parameters that will be measured during study of the HPR performance include the following: feedstock composition and flow rate; pressure differentials with varying heights in the reactor, across the cyclone, and across the hot gas filter; reactor temperature; reactor gas outlet composition, temperature, and pressure; and composition of the bottom ash and filter ash. Noncritical measurements will include pressure of the inlet gases, overall system pressure, and miscellaneous data such as time, date, and ambient temperature.

1.2.2 Project Operation Dates

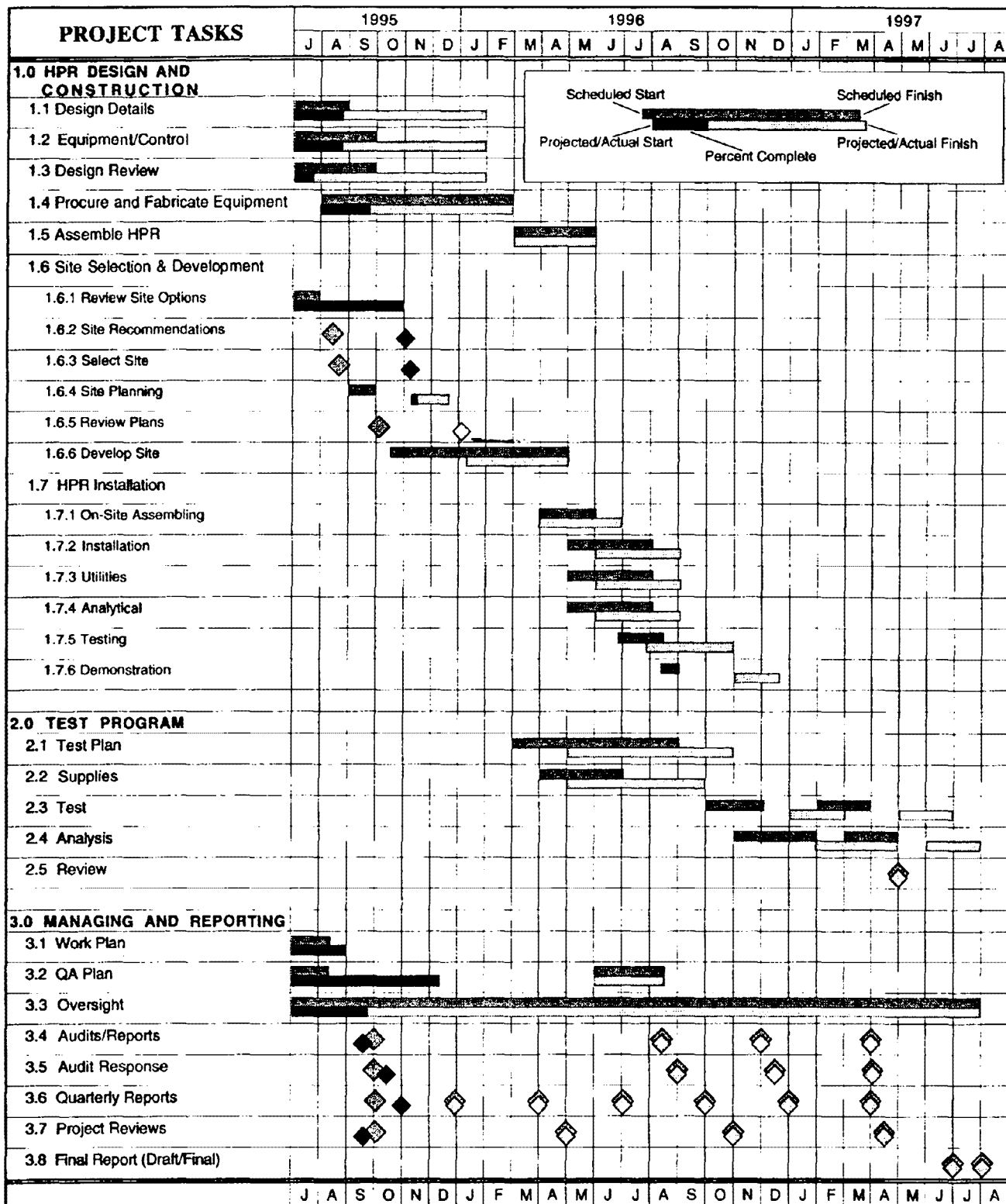
Pending completion of construction of the pilot HPR on schedule, testing will be conducted beginning in September 1996 and ending in March 1997.

Table 1-1. Candidate gasifier configuration and operating conditions

| | Feed system | Feed stock | Gasifier conditions | Alkali getters | Filter type | Filter operation ^a |
|---------------------------------------|---|---|---|--|---|--|
| Test variable | Metering bin, screw feed, lock hopper system | Clean wood chips • Military waste • Landscape/tree trimming waste • Energy crops - Poplar - Switch grass - Eucalyptus | • Recycle gas representing two process models • Recycle gas plus steam and natural gas | • Mixtures of: Emathalite Kaolinite Sand • Alternate bed materials | • Pall ceramic candle • Pall sintered metal candle • Water scrubber • Other filter | • P ₁ , T ₁ , S _{1,2} • P ₂ , T ₁ , S _{1,2} |
| Activities and data collection | Lock hopper and feeder performance, Pressure-gas requirements | Feedstock analysis, physical properties, particle size, chemical composition | Feed gas composition, thermodynamic state, output composition, carbon conversion, reaction kinetics | Refractory chemistry, fate of alkali | Filter mechanics and chemistry, filter performance | Filter performance, output gas loading |

^aP= Reservoir pressure, T= Reservoir temperature, S= Pulse cleaning schedule (duration and timing)

Figure 1-2. Schedule



SECTION 2

PROJECT ORGANIZATION AND RESPONSIBILITIES

CE-CERT and the Acurex Environmental Corporation have assembled a project team that provides the process technology and pilot plant design, construction, and operation experience and support to ensure the success of this project. The team is staffed with personnel selected based on their specific related experience.

The project organization chart is shown in Figure 2-1. Dr. George Hidy is the Project Principal Investigator. Dr. Hidy is responsible for all data generated in the project, for all corrective action, for the technical quality of the project work, for review of the laboratory data, and for integration of the data into the final report. Mr. Stefan Unnasch is the Acurex Project Manager, and is responsible for the construction and operation of the HPR in Phase I. Mr. Kent Johnson is the Project Engineer for CE-CERT, and is responsible for coordinating the site construction by working with the UC Riverside campus, Acurex, and associated contractors. He will also coordinate the sampling and analysis efforts. Mr. Hans Dehne is the Acurex Engineering and Design Reviewer for this project. The Quality Assurance (QA) Reviewer for CE-CERT is Mr. John Collins, who is supported by Libby Beach, Quality Assurance Reviewer for Acurex.

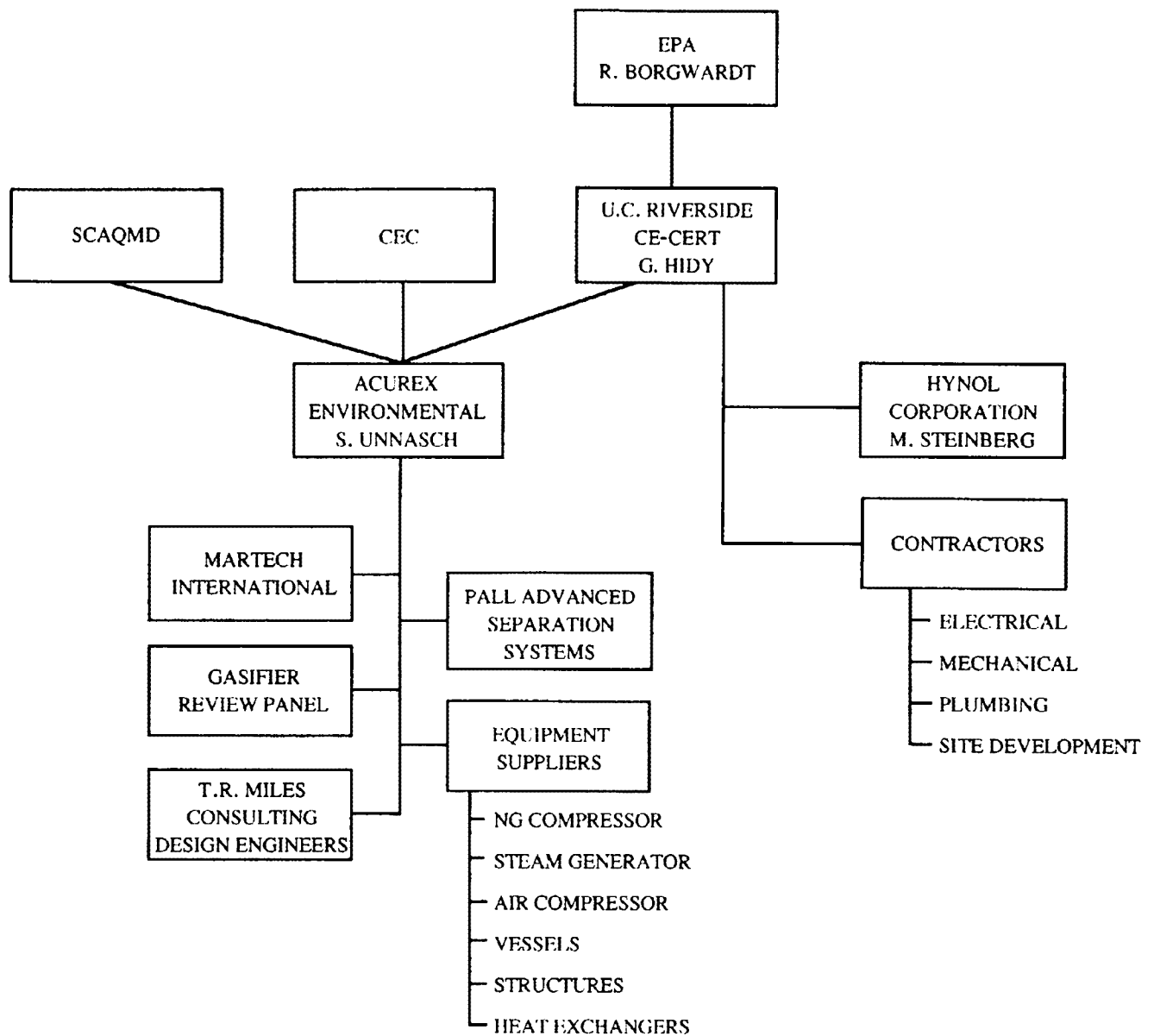


Figure 2-1. Project Organization

SECTION 3

DATA QUALITY INDICATOR GOALS FOR CRITICAL HPR MEASUREMENTS

The main objectives of Phase I are:

- To demonstrate the performance of a high pressure fluidized bed hydrogasifier as a practical means of providing methane rich product gas to a steam reformer process
- To demonstrate a maximum carbon conversion under simulated optimum recycle gas conditions of a steam/carbon ratio estimated to be between 2.5 and 3.5 in the SPR
- To demonstrate the HPR system capability to operate without external energy sources other than feed stream enthalpy
- To feed and gasify biomass material in the HPR without agglomeration problems
- To generate data for scale up of an HPR as a 10 tons/day facility
- To develop a biomass feed system and test its durability in the HPR environment
- To demonstrate alkali metal adsorbing materials that successfully mitigate gasifier problems
- To successfully test a hot gas clean up system suitable for the HPR system, including removal of particulates and H₂S

To meet these objectives, the accuracy and precision of the critical measurements (i.e., flow rate, absolute pressure, pressure differentials, temperature, and gas and solid compositions) must be ensured to an appropriate degree. The detailed sampling and analysis plan will be prepared for review and acceptance after the HPR system is assembled and commissioned. The plan for initial testing will depend on available funding resources.

Qualitatively, the accuracy of the data can be judged by the degree of closure of the overall mass balance for the HPR. Accuracy and precision will also be evaluated quantitatively, as discussed in Section 7.

SECTION 4

SAMPLING PROCEDURES FOR THE HPR

4.1 HPR Operating Conditions

The HPR will be operated over a range of conditions to provide data to meet the objectives discussed in Section 3. Gas compositions will be varied to evaluate different Hynol process configurations. Varying steam and natural gas feed levels to the HPR and recycle gas temperature will also simulate different process configurations. Solids feed will be varied to evaluate the effect of different thermochemical properties which are affected by wood type and moisture content; alkali, sulfur, and contaminants which are affected by feed type; and physical properties which are affected by particle size and shape.

Table 4-1 shows candidate test conditions for HPR testing. Initial testing will consist of the most favorable operating conditions for the HPR. It is anticipated that two feedstock specifications and two gas compositions will be tested. These conditions include using clean white wood as a feedstock, no natural gas feed prior to the HPR, and moderate steam feed to the HPR. Table 4-1 shows the solids and gaseous feeds to the HPR. Feeding steam prior to the HPR (and prior to the inter-heat changer) has the advantage of reducing the potential for soot formation and also allows for a greater level of heat recovery. The disadvantage is that adding steam reduces the maximum achievable temperature for the recycle stream. The final test matrix will depend on the level of funding for HPR operation.

The biomass feed is indicated by the feedstock code in Table 4-1 which corresponds to the target feedstock properties in Table 4-2. Actual feedstock properties will be based on the availability of wood and the performance of the feed processing system. Preliminary estimates of bed materials are also shown in Table 4-1. Bed material and make-up rates will be adjusted with HPR operating experience.

The specifications for feed gas flow rates are also shown in Table 4-1. The composition, flow rate, and temperature of the recycle stream can be adjusted to reflect different Hynol process configurations. Inlet steam and natural gas feed rates can also be adjusted to reflect different configurations. The gas feed conditions will be based on process simulation models performed by EPA or Acurex Environmental. Process simulations indicate the gas properties for the integrated Hynol system. For the independently operated HPR system, these properties will be simulated by mixing tube trailer gases, natural gas, and steam.

The HPR will be operated over a series of one-week periods with around the clock operation for 5 days. The first day will be for facility startup. Depending on achievement of steady state operation, three to four days should be available for data collection. It is expected that data will be generated for 10 to 16 4-hour data collection periods over a 4-day test period. Gas compositions that represent other process models can be readily tested if the HPR operates over a 4-day period as planned. Steam and natural gas input as well as HPR recycle gas temperature, composition, and flow rate can be varied while the HPR is operating to simulate different operating conditions. It is expected that

biomass properties will be held constant for the one-week operation period; however, the biomass moisture content or particle size could also be varied within the week of operation. Current plans call for testing waste materials such as tree trimmings after experience is gained on clean wood (CW).

Table 4-1. HPR test conditions

| Test condition | CW1 | CW2 | CW3 | CW4 | CW5 |
|--|------|------|------|------|------|
| Solids feed | | | | | |
| Feedstock | B1 | B2 | B1 | B2 | G1 |
| Feed rate (kg/h) | 25.8 | 25.8 | 25.8 | 25.8 | 25.8 |
| Make up sand (g/h) | 300 | TBD* | TBD | TBD | TBD |
| Initial sand (kg) | 2 | TBD | TBD | TBD | TBD |
| Gas feed, HPR inlet | | | | | |
| Process simulation | 1 | 2 | 1 | 2 | 1 |
| Recycle gas | R1 | R2 | R1 | R2 | R1 |
| Recycle flow rate (kmol/h) | 5 | TBD | 5 | TBD | 5 |
| Temperature (°C) | 800 | TBD | 800 | TBD | 800 |
| Steam flow rate (kmol/h) | 0.7 | TBD | 0.7 | TBD | 0.7 |
| Natural gas flow (kmol/h) | 0.3 | TBD | 0.3 | TBD | 0.3 |
| Total flow (kmol/h) | 6 | TBD | 6 | TBD | 6 |
| Enthalpy (kJ/kg) | TBD | TBD | TBD | TBD | TBD |
| Enthalpy (kJ/h) | TBD | TBD | TBD | TBD | TBD |
| Total feed (biomass & feed gas) | | | | | |
| Enthalpy (kJ/h) | TBD | TBD | TBD | TBD | TBD |
| Carbon feed (kg/h) | 12 | TBD | 12 | TBD | TBD |
| Minimum run time (h) | 4 | 4 | 4 | 4 | 4 |
| Repeats | 2 | 1 | 1 | 1 | 2 |

*TBD = to be determined

Table 4-2. Target properties for biomass feedstocks

| Biomass feed | B1 | B2 | G1 |
|----------------------|-----|-----|------------|
| Material | Fir | Fir | Tree chips |
| Typical chip size | | | |
| Min (mm) | 2 | 3 | 3 |
| Max (mm) | 10 | 15 | 15 |
| Moisture (wt%) | 12 | TBD | TBD |
| Ash (wt%) | TBD | TBD | TBD |
| Carbon (dry wt%) | TBD | TBD | TBD |
| Carbon (kg/total kg) | TBD | TBD | TBD |
| Enthalpy (kJ/kg) | TBD | TBD | TBD |

Table 4-3 shows the feed gas parameters for the integrated Hynol process simulation model and the HPR system. The gas flow rates and temperatures for the HPR system are based on the following principles:

- Steam added to the HPR simulates both water vapor in the recycle stream and steam feed.
- H₂, CO, CO₂, N₂ and steam are heated in an electrical heater.
- Natural gas added after the heater simulates both methane in the recycle stream and natural gas feed.
- H₂ and CO simulate methanol in the recycle stream as the methanol would dissociate in the heat exchanger prior to feeding into the HPR.
- The net enthalpy of feed gases entering the HPR is adjusted by varying the exit temperature of the gas heater.
- Feed gas enthalpy can be increased to take into account heat losses from the bench scale system.

For each feed gas configuration, the HPR system flow rates will be calculated from the simulation model conditions as indicated in Table 4-3. The temperature of the gas heater can be adjusted to take into account heat losses from the bench-scale system that exceed those from a commercial system.

The enthalpy for the biomass feed will be calculated from the measurements of heating value, composition, and moisture content. Total enthalpy and carbon feed will be calculated from feedstock analyses.

4.2 Sampling and Analysis Procedures

Characterizing the performance of the HPR will require a variety of measurements to characterize the operating conditions, the physical and chemical properties of feedstocks, waste ash, effluent gases and particles, and the mechanical performance of the high temperature filter. Measurement methods for each of these categories are discussed briefly below. In some cases, especially where gas or aerosol sampling at high temperature and pressure is involved, standard methods available may not be adequate for the system testing. Non-standard specialized methods will be needed. These have not been specified at this time, and will be determined prior to initiating the test program. The system components to be tested, the quantities to be measured, and the measurement methods to be used are summarized in Table 4-4. The procedures used to calibrate the identified methods and the accuracy and precision of the methods are summarized in Table 5-1. The number of samples to be taken and analyzed has not been determined. The frequencies identified below are estimates, to be revised based on operating conditions and initial test results.

Measurements of parameters for continuous measurements will be taken at locations specified in the P&ID for the HPR shown in Figure 4-1. The location and designation of thermocouples and pressure transmitters are indicated in the Figure. Table 4-5 shows the instrumentation for collecting continuous flow data from the HPR system. Each flow rate includes a measurement of temperature, pressure drop (dP) across an orifice, and inlet gas pressure. Flow rate calculations are discussed in Section 6.

Table 4-3. Feed gas parameters

| Modeled integrated Hynol system -- HPR Inputs | | | | | | |
|---|---------------|---------------|--|----------------|---------------|--------------|
| Simulation No. | | 1 | SPR H ₂ O/CH ₄ = 2.0 | | RBA1094 | |
| Recycle Temp (°C) | | 760 | Enthalpy | | MW | |
| <u>Recycle</u> | (vol %) | (kmol/h) | (kg/h) | (kJ/h) | (kJ/kmol) | (g/mol) |
| H ₂ | 62.5 % | 2.65 | 4.66 | 57.5 | 21.7 | 2.02 |
| CO | 9.7 % | 0.41 | 10.08 | -35.9 | -87.6 | 28.01 |
| CO ₂ | 5.8 % | 0.25 | 9.24 | -89.5 | -358 | 44.01 |
| CH ₄ | 7.3 % | 0.31 | 4.33 | -10.48 | -33.8 | 16.04 |
| H ₂ O | 12.3 % | 0.52 | 8.29 | -111.8 | -215 | 18.02 |
| N ₂ | 1.4 % | 0.06 | 1.46 | 1.36 | 22.6 | 28.01 |
| CH ₃ OH | 1.0 % | 0.04 | 1.18 | -6.0 | -150 | 32.04 |
| Total | 100.0% | 4.24 | 39.24 | -194.8 | -45.8 | 10.63 |
| Steam Temp (°C) | | 235 | | | | |
| Steam | | 0 | 0 | 0 | -236 | 18.02 |
| CH ₄ Temp (°C) | | 25 | | | | |
| CH ₄ | | 0 | 0 | 0 | -74.9 | 16.04 |
| Total flow | | 4.24 | 39.24 | -194.8 | -45.8 | 10.63 |
| H | | 7.752 | 7.83 | | | 1.01 |
| C | | 1.013 | 12.17 | | (kJ/kg) | 12.01 |
| N | | 0.120 | 1.68 | | -4.99 | 14.01 |
| O | | 1.473 | 23.57 | | | 16.00 |
| Total | | 10.358 | 45.25 | | | - |
| HPR system, Gaseous inputs | | | | | | |
| Stream 68a Temp (°C) | | 820 | Enthalpy | | MW | |
| <u>Stream 68a</u> | (vol %) | (kmol/h) | (kg/h) | (kJ/h) | (kJ/mol) | (g/mol) |
| H ₂ | 68.12% | 2.74 | 5.52 | 64.58 | 23.57 | 2.02 |
| CO | 11.19% | 0.45 | 12.6 | -38.52 | -85.61 | 28.01 |
| CO ₂ | 6.2% | 0.25 | 11.0 | -88.75 | -355 | 44.01 |
| H ₂ O | 12.9% | 0.52 | 9.37 | -110.33 | -212.17 | 18.02 |
| N ₂ | 1.49% | 0.06 | 1.68 | 1.48 | 24.64 | 28.01 |
| Total | 100.0% | 4.02 | 40.17 | -171.5 | -42.54 | 9.98 |
| Nat. gas Temp (°C) | | 25 | | | | |
| Natural gas | | 0.31 | 4.97 | -23.26 | -75 | 16.04 |
| Bench scale system heat losses | | | | 0 | | |
| Total | | 4.33 | 45.14 | -194.76 | 44.9 | 10.4 |
| H | | 6.51 | 6.58 | | | 1.01 |
| C | | 0.70 | 8.40 | | (kJ/kg) | 12.01 |
| N | | 0.12 | 1.68 | | -5.42 | 14.01 |
| O | | 1.47 | 23.52 | | | 16.00 |
| Total | | | 40.18 | | | - |

Bold values are input, others are calculated. Enthalpy values need to be based on formulae.

Table 4-4. Data collection requirements for the HPR system

| Data Type | Measurement | Procedure |
|---------------------------|--|---|
| Continuous flow data | H ₂ , CO, CO ₂ , H ₂ O, N ₂ , Natural gas, make up N ₂ , HPR effluent flow rate Temperature Pressure | Orifice plate with dP ^a transducer, P transducer, type K thermocouple Type K thermocouple Pressure transducer |
| Continuous operating data | HPR bed pressure drop HPR bed temperature profile Filter pressure drop Cyclone pressure drop Solids feed rate | dP transducer dP transducer dP transducer dP transducer Metering screw controller |
| Gas samples | HPR effluent composition (CO, CO ₂ , CH ₄ , C _x H _y .) (H ₂ , N ₂ , O ₂) (H ₂ S) | Sample collection into canisters based on EPA Method 5 and/or CARB Methods 15 AND 16 GC/FID SCAQMD 25.1 GC/TCD NIOSH Tubes |
| Process Particulates | Mass Metals | Sample extraction based on EPA Method 5 followed by gravimetric analysis AA |
| Ash Samples | Tar content Carbon content Morphology Particle size Alkali content | To be determined To be determined Microscopy Coulter Counter AA |
| Feedstock composition | Ultimate analysis Proximate analysis Metals Content | Refer to Section 5 Refer to Section 5 AA |
| Feedstock properties | Heating Value Density Bulk density | Refer to section 5 Gravimetric Gravimetric |
| Materials analysis | Surface analysis Ceramic candle strength Sintered metal candle porosity | Scanning electron microscope C-ring compression, tension Porosity bubble test |

^a dP = differential pressure

Appropriate chain of custody procedures will be employed to ensure the proper disposition and analytical procedures for grab samples. Chain of custody forms and procedures will be discussed in a QA plan revision to be prepared early in the second year of the project.

Input Gases

Input gases are pure streams of H₂, CH₄, CO₂, CO, N₂, and H₂O as steam. The compositions of the input gases will not be tested prior to injection into the system. The specifications provided by the gas suppliers will be used for composition data.

Input gas flow rates will be measured using orifice meters permanently installed in the inlet lines. Permanently installed thermocouples and pressure transducers will be used to monitor gas temperature, gas pressure, and orifice pressure drop. These quantities will be monitored continuously during each test using a data logger.

Solid Feedstocks

Biomass feedstocks for initial testing will be produced on-site by controlled chipping of a single batch of lumber adequate to supply feedstocks for a two week test period. Therefore, sampling and analysis of the feedstock will only be conducted on a per test basis. Three or more 100 cm³ samples will be selected from various locations within the feedstock storage pile and sent to commercial laboratories to determine basic physical and chemical properties, and provide a measure of feedstock variability. The physical properties include density and heating value. Proximate chemical properties include percent moisture, percent volatiles, percent ash, and percent fixed carbon. Ultimate chemical properties include percent by weight of various elements, including; C, H, O, N, S, Na, K, Mg, and Ca. The critical measurements needed for assessing carbon conversion efficiency are the feedstock density and the percent carbon by weight. The imprecision in feedstock composition due to feedstock non-uniformity and analytical uncertainties will be estimated by analyzing the results for the multiple samples. The accuracy of feedstock composition determinations will be assessed by reviewing laboratory results for their in-house analysis of standard materials.

Feedstock flow rate will be controlled by a specially designed screwfeeder system that will provide constant volume delivery rates. The precision and accuracy of the screwfeeder delivery rate will have been characterized by the manufacturer when operating at ambient temperatures and pressures. The accuracy and precision of screwfeeder delivery rates during test operations will be assessed by measuring the volume and/or weight of biomass feedstock delivered to the inlet hopper during a test.

Solid feedstocks of kaolinite and sand also will be supplied to the system during the test. Measurement of composition and flow rate are not critical to carbon balance calculations. They are useful operating parameters and needed for overall mass balance calculations that include ash outputs. The composition of these materials will not be analyzed, but will be determined from the supplier assays, or from standard reference books. The feed rate will be determined by adding known volumes.

Output Gases

The effluent of the HPR will consist of a mixture of gases, including hydrogen, methane, carbon monoxide, carbon dioxide, and water vapor. Measuring the carbon content and flow rate of the HPR effluent stream is critical to carbon balance calculations. Obtaining additional speciation, and measuring the effluent temperature, pressure and flow rate are also critical to the energy balance calculations. Additional measurements of trace materials such as hydrogen sulfide and non-methane hydrocarbons are not critical for carbon balances but are useful operating parameters for characterization of pollutant or contaminant release. The composition of the HPR effluent gas has been modeled during the process design phase of this project. A breakdown by percent volume is shown in Table 4-5 to illustrate the nature of the analyses required. Gas samples will be collected and analyzed once for each set of test operating conditions that reach steady state. The number of samples will be specified later as part of a final test plan prepared prior to the initiation of the testing. Steady state operation of the HPR has yet to be defined because no such system has been operated. It is anticipated, however, that preliminary tests will be conducted on the system to establish a time interval to reach steady state conditions as determined by temperature monitoring and compositions monitoring of major gas constituents in the effluent.

Table 4-5. Example design composition of HPR effluent gas

| Species | Volume % |
|------------------|----------|
| H ₂ | 37% |
| CO | 13% |
| CO ₂ | 8% |
| CH ₄ | 19% |
| NMOC | <1% |
| N ₂ | 2% |
| H ₂ O | 20% |
| H ₂ S | 0.03% |

Gases will be extracted from the processes stream at sampling port SP-825, and measured using a combination of continuous and canister sampling techniques adapted from stationary source sampling methods. Several factors combine to preclude the straightforward application of standard source sampling methods. These include the high pressure (30 atm), high water content (20% by vol), and small process pipe diameter (1" NPT). Different sampling strategies will be required for different components of the gas stream. Engineering details of the sampling system have not yet been designed. The basis of the sampling methods is described below.

The sample collection system will include a sample extraction system consisting of a water cooled sampling line, ball valve, filter for particle removal (not to be analyzed), and regulating valve to

reduce sample pressure to atmospheric. All components of the system will be made of corrosion resistant materials and will be maintained at a temperature above 200°C to prevent moisture condensation. Components upstream of the regulating valve will operate at the pressure of the reactor piping (30 atm). Various gas sampling systems will be attached to the output of the regulating valve.

Water vapor will be analyzed by passing the sample through a cooling system and quantitatively collecting the condensed water using methods based on EPA Method 5 or (one of its state or local variants).

H₂S will be analyzed by quantitative dilution of the gas stream with clean dry gas, cooled, and then sampled using NIOSH sampling tubes. In order to avoid loss of H₂S, the sample gas must not be passed through the condensing system used for determination of water vapor.

The output of the condensing system or the output of the dilution system will be analyzed for CO, CO₂, CH₄, and non-methane organics (NMOC) by collection into canisters and subsequent analysis by GC/FID, following procedures based on California South Coast Air Quality Management District (SCAQMD) Method 25.1. The concentrations of carbon gases in the effluent are higher than the concentration ranges that Method 25.1 was designed for. CE-CERT will work with the GC equipment manufacturer to determine the maximum working ranges for these compounds. If the instruments are capable of quantifying these compounds at high concentration, then the instruments will be calibrated and used at these high ranges. If the effluent concentrations are too high for the GC, then the canister samples will be diluted quantitatively, and standard calibration ranges will be used. The methods discussed above are straightforward for the single carbon gases, but controversial for NMOC.

Sampling NMOC from hot gas streams is a complex issue involving operational definitions of condensable versus gas-phase compounds, and significant potential for loss of volatile gases to the walls of sampling equipment. It is currently the subject of ongoing research efforts. For this project, the concentration of NMOC is expected to be very low compared with the concentrations of single carbon gases, and is not likely to be a significant factor in the carbon or energy balances. The quantification of NMOC will be considered non-critical, and the results provided by standard sampling methods accepted with the understanding that potential problems may be encountered which are not identified at this time.

The non-carbon gases H₂, O₂, and N₂ collected in the canister will be analyzed by GC/TCD. Current plans are to subcontract these analyses to a commercial laboratory. If the number of samples provided by this and other projects justifies it, then GC/TCD sampling equipment will be leased or purchased by CE-CERT.

At the option of CE-CERT, depending on the availability and cost of equipment, continuous monitoring of CO and CO₂ will be implemented in addition to the canister samples. Samples would be continuously extracted from port SP-825, cooled, and dried, using either the water condenser system or the dilution system. The continuous CO and CO₂ measurements would not be used for

carbon or energy balance calculations. They would provide a means of monitoring operating conditions for determination of steady state and the variability of gas concentration at apparent steady state. These monitors also would provide a cross-check of canister/GC results.

Output Solids

The HPR test system includes three hoppers and a baghouse for collection of solids. Reactor bed materials are collected into one hopper from the base of the HPR reactor, and into another hopper from the upper portion of the reactor. Suspended particles are removed from the effluent of the HPR cyclone by a high temperature filter candle, and the collected particles are stored in the vessel until the end of the test. Suspended particles remaining in the process flow downstream of the filter candle are not collected; they are flared.

For this study, ash samples will be collected from the three hopper systems: reactor bottoms, top of bed, and filter candle catch. Hoppers will be emptied at the beginning of a test run. At the end of a sample run the hopper contents will be weighed, and samples collected into glass jars. The ash samples will be shipped to a commercial laboratory for analysis of: Na, K, Ca, Mg by AA; and for total carbon by carbon analyzer. A subset of samples will be taken to analyze the ash for speciated organic compounds using GC/MS. Selected samples of ash will be sent to Pall Corp. for determination of particle size distribution using Coulter counters and for determination of particle morphology using SEM.

Process Measurements

In addition to the measurements necessary to determine process inputs and outputs, additional measurements of process operating parameters will be made at various points throughout the system. These process measurements are not critical to determining carbon or energy balances, but are used to assess and control the operation of the fluidized bed, cyclone, filter, heat exchanger, steam generator, etc. With one exception, they consist of temperature, pressure, and pressure drop measurements which will be monitored continuously using thermocouples, pressure transducers, and pressure drop transducers. One in-process measurement poses special problems: measurement of suspended particle loading upstream of the filter candle. Particulate samples will be collected from port SP-817. In addition to measuring particulate mass, the metals content of the particulate will also be determined. The method employed to collect the sample and determine total particles will be an adaptation of EPA Method 5 for stationary source testing (or one of its state or local variants). The metals will be analyzed by AA for Na, K, Ca, and Mg. If possible, a subset of particle samples will be obtained for size distributions using modifications of California Air Resources Board (CARB) Method 501.

Method 5 calls for drawing a sample through an isokinetic probe in the process stream, then through a specially lined sampling line and filter maintained at 120°C, followed by a series of impingers maintained at 0°C containing water, empty, and silica gel, and finally through gas metering equipment. Total Particulate for the purpose of Method 5 includes particles and condensables other than water that are caught in the probe tip, sampling line, filter and impingers. Method 5 also calls

for measurement of process stream velocities using pitot tubes and collecting from various locations within the process stream.

In this study, the particulate loading in the process upstream of the filter candle will be used to help determine filter candle requirements, and will be used to assess the effects of different operating conditions on the expected life of the filter and on the requirements for the filter. Thus, Method 5 will be modified to focus on the particulate concentration at high temperature. In particular, condensables are not important. The method has not yet been determined and will depend on engineering details of the process piping and on the availability of commercial sampling equipment. Samples are planned to be taken through an isokinetic probe, a ball valve, a filter, an orifice meter, and a flow regulating valve, in that order, all maintained at moderately high temperature. This obviates the need for specially lined sampling lines and the need for impingers to determine the mass of water vapor and condensables. Flow velocity in the process pipe will be estimated from the continuously monitored volumetric flow rate of the process rather than from pitot tubes. This leaves the problem of particles impacting in the isokinetic probe tip. Method 5 calls for the removal of the probe and collection of these particles. Implementation of the method will require design of a removable probe system, or a straight probe configuration to eliminate particle impaction losses.

Method 501 calls for drawing the sample through an isokinetic probe, a cascade impactor system, then through water collection and gas flow metering equipment. Due to the high sample pressure, implementation of Method 501 will require the design of a removable probe or a straight through probe, and the use of a cascade impactor that can withstand 30 atm. It has not been determined if cascade impactors capable of operating at this pressure are available. This will be done as a part of the final test plan to be assembled prior to the testing program.

Structural Measurements

At the conclusion of the HPR test cycle, structural components of the system will be examined for the effects of temperature and pressure cycling, corrosion, and abrasion. Components such as the refractory, filter candles, and exposed metal will be examined microscopically for physical characteristics. Small samples of material will be obtained for the analysis and sent to commercial laboratories for evaluation. The filter candle will be returned to the manufacturer, Pall Corp., for surface analysis by SEM, mechanical strength by C-ring compression test, and for porosity by bubble test.

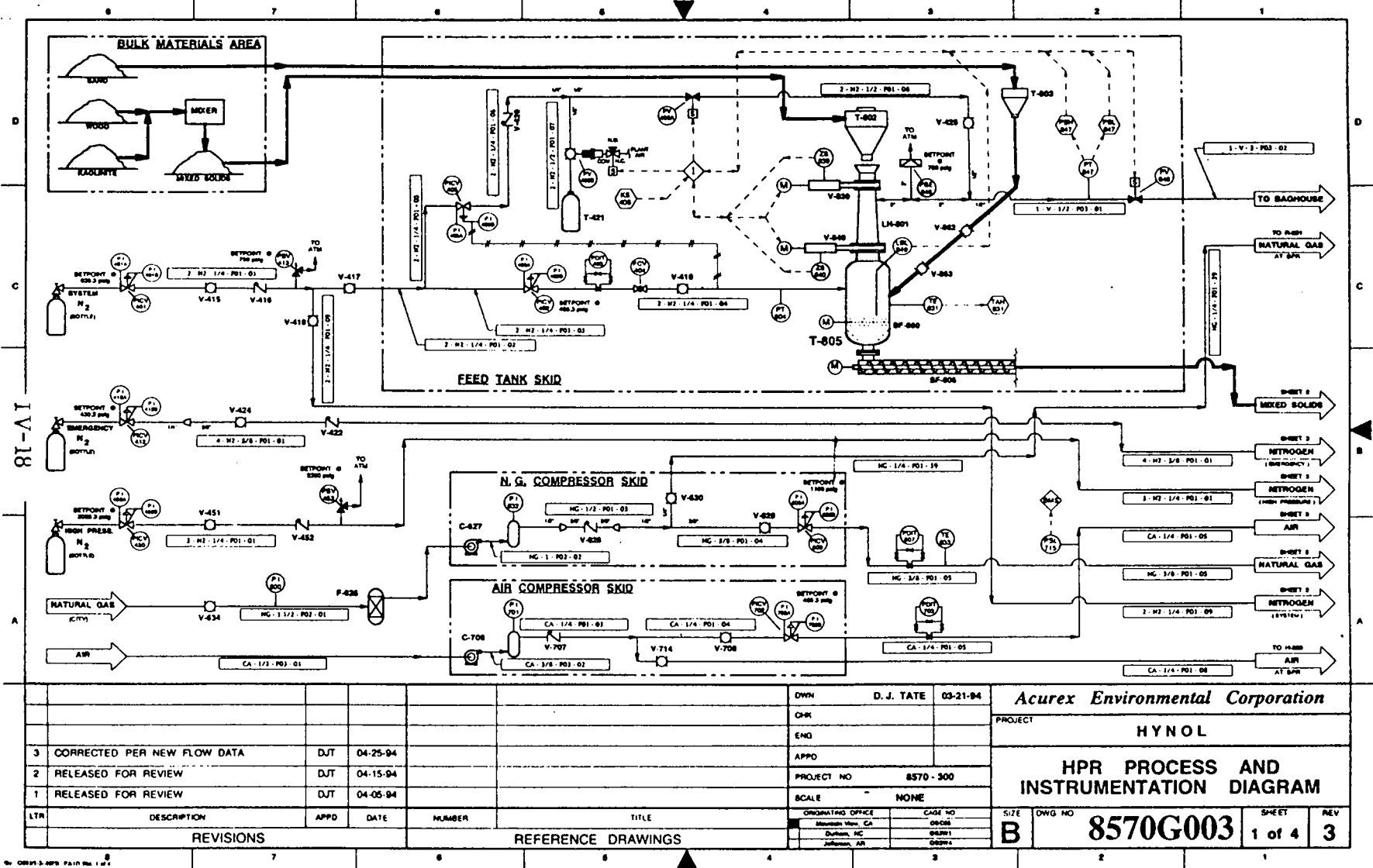
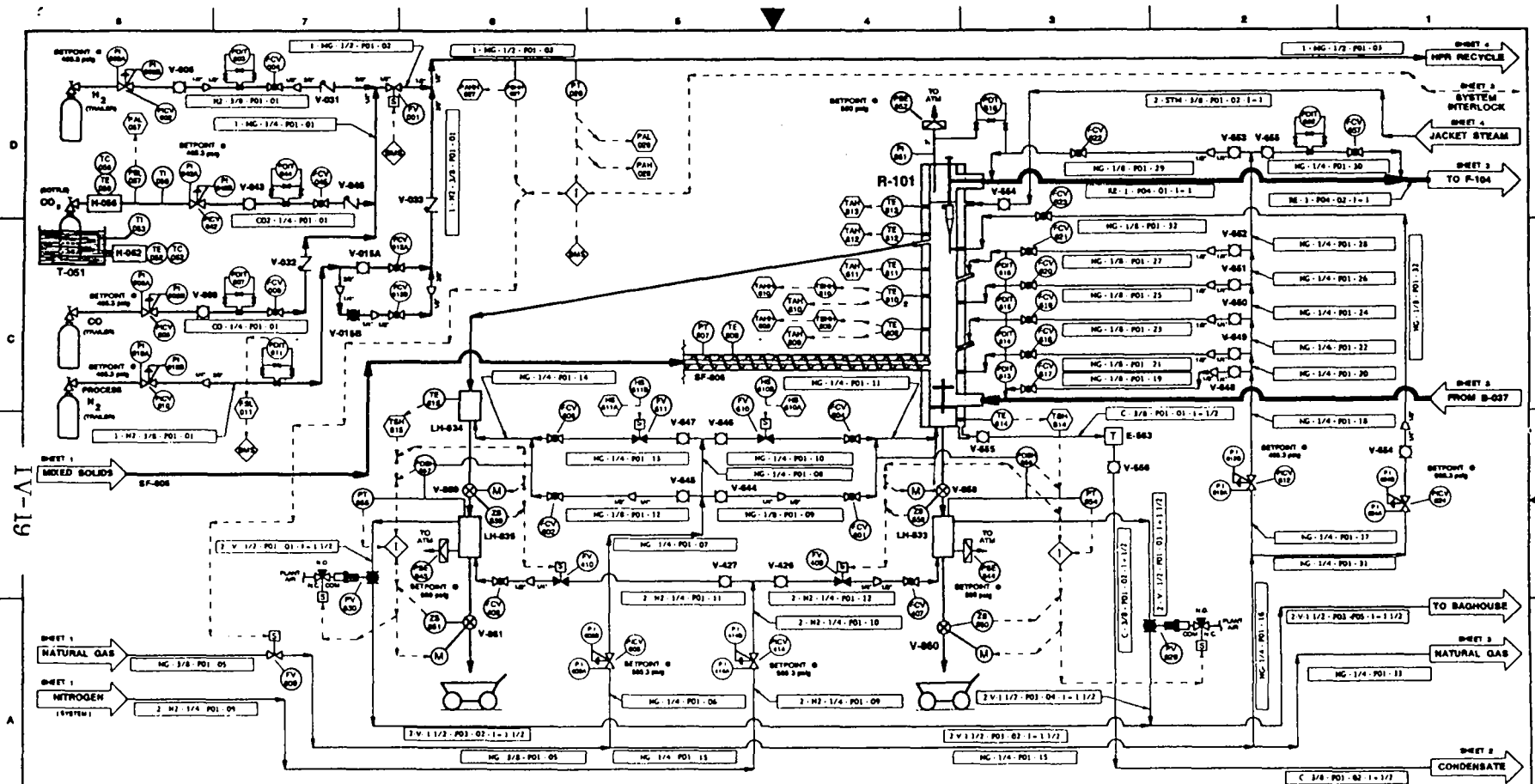


Figure 4-1. HPR P&ID



| | | | | | | | | | | | | |
|-----|-----------------------------|------|----------|--------|--------------------|---|----------------|----------|--|--------|-----|--|
| | | | | | | DWN | D. J. TATE | 03-21-84 | Acurex Environmental Corporation | | | |
| | | | | | | CHK | | | PROJECT | | | |
| | | | | | | ENG | | | HYNOL | | | |
| 3 | CORRECTED PER NEW FLOW DATA | DJT | 04-25-84 | | | APPD | | | HPR PROCESS AND INSTRUMENTATION DIAGRAM | | | |
| 2 | RELEASED FOR REVIEW | DJT | 04-15-84 | | | PROJECT NO | 8570 - 300 | | | | | |
| 1 | RELEASED FOR REVIEW | DJT | 04-05-84 | | | SCALE | NONE | | | | | |
| LTR | DESCRIPTION | APPD | DATE | NUMBER | TITLE | ORIGINATING OFFICE | CAGE NO | SIZE | OWG NO | SHEET | REV | |
| | REVISIONS | | | | REFERENCE DRAWINGS | Mountain View, CA Durbin, NE J.E. | 08048 88791 | B | 8570G003 | 2 of 4 | 3 | |

Figure 4-1. HPR P&ID

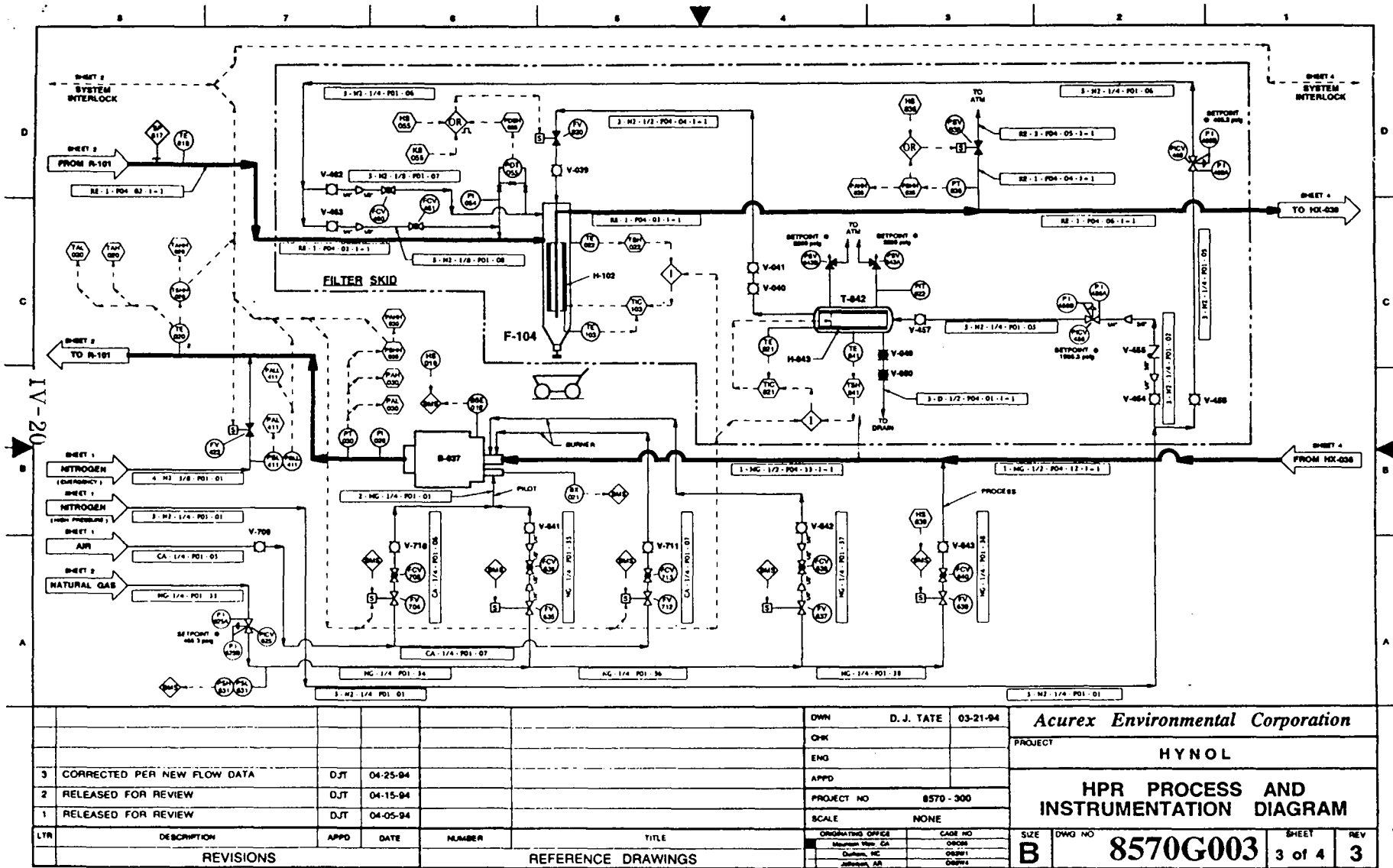


Figure 4-1. HPR P&ID

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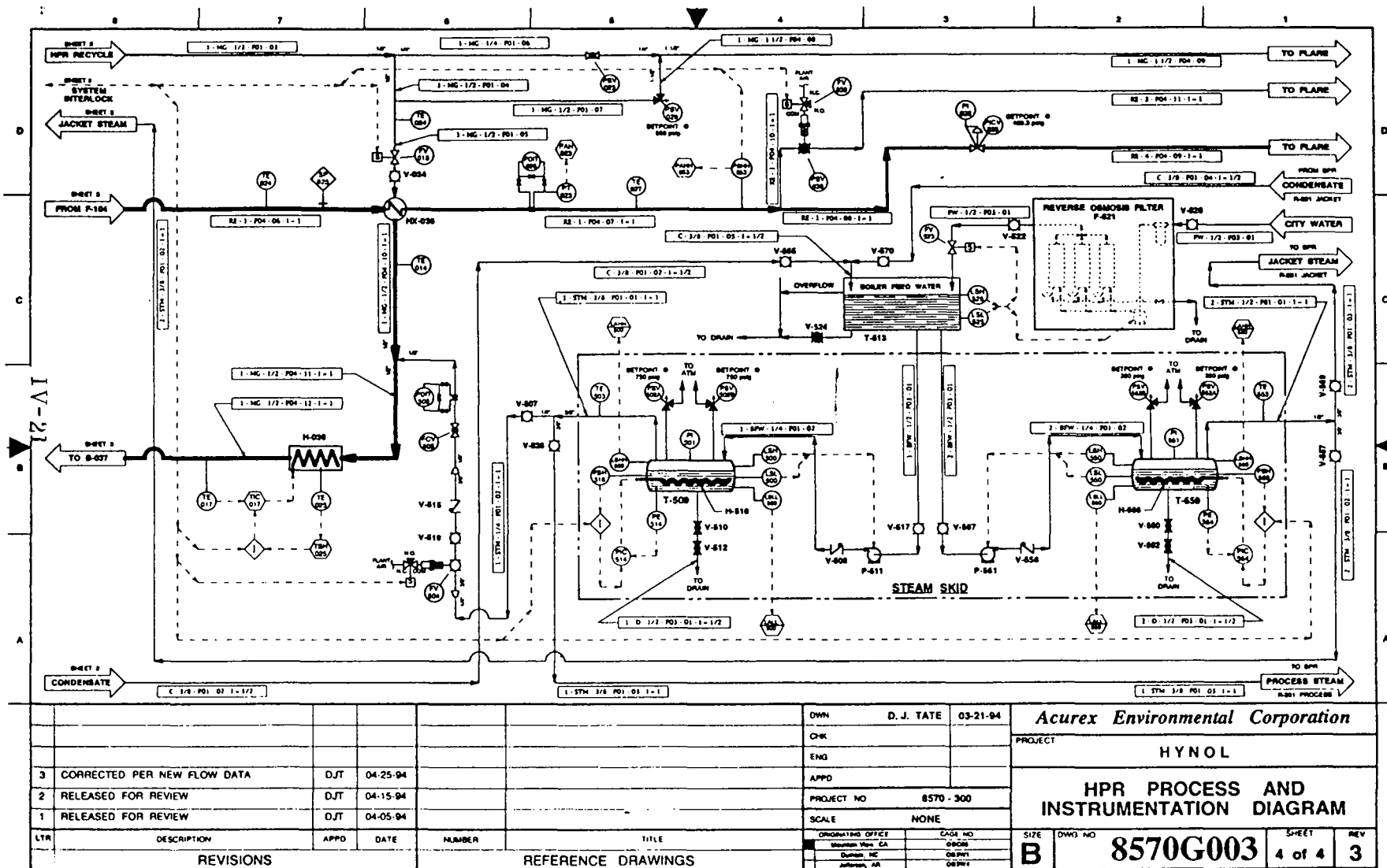


Figure 4-1. HPR P&ID

SECTION 5

ANALYTICAL PROCEDURES FOR THE HPR

Laboratory analytical procedures will either follow or be adapted from those of standard methods published by ASTM, EPA, CARB, or SCAQMD. To ensure the accuracy of the data, calibration frequencies and tolerances will meet or exceed the requirements prescribed in the standard methods, and the analytical laboratories will be challenged with QA standards procured or prepared separately from the calibration standards. Quality control measures include duplicate sample collection, replicate sample analyses, zero checks, and span checks. The analytical procedures for measuring each parameter and the appropriate standard or calibration method are listed in Table 5-1.

Continuous Data

Instruments such as thermocouples, orifice plates, and differential pressure transducers are pre-calibrated by the manufacturer. Temperature and pressure transducers will be checked before each HPR start by comparing instrument readouts at ambient temperature and pressures with laboratory thermometers and barometers. Pressure difference transducers will be checked by comparing against a manometer. Orifice plate flow rates calculated from delta pressure will be compared with dry test meter flow rate measurements made at ambient temperature and pressure.

Gas Samples

Analysis of carbon containing gases from the sample canisters will follow procedures in SCAQMD 25.1. In this method, an aliquot of gas sample is separated into CO, CO₂, CH₄, and NMOC fractions, by capillary column GC, oxidized to CO₂, reduced to methane, and detected using FID. A zero plus 2 point calibration is performed once each morning. A 1-point calibration check and a replicate sample analysis is performed every fifth run. Gas samples will be analyzed within three days of acquisition. Method 25.1 is not designed to cover the range of high concentrations expected for the HPR study. The method will be adapted by using high concentration range standards, and by using small sample aliquot loops. If the concentrations are still too high, the gases will be quantitatively diluted. Dilution is done using a static system quantified by accurate measurement of mixing vessel pressure. Procedures, calibration, and QC results will be regularly reviewed and summarized by the QA coordinator. These summaries will be reported with the data. The target uncertainty for carbon gas measurements is the larger of: 2% of the measured concentration; or 0.1% by volume, i.e. +/- 1000 ppm.

Analysis of H₂, N₂, and O₂ will be by GC/TCD. A packed column GC will be set up at the CE-CERT laboratory. A mixed calibration standard will be purchased from a specialty gas supplier. Precision will be assessed by replicate analyses. Target uncertainty for these analyses is +/- 0.5% by volume, i.e., +/- 5000 ppm.

Accuracy of analysis for H₂S will rely on the manufacturer's stated specifications for the hand-drawn gas sample tubes. Precision will be assessed by replicate analyses.

Biomass Feedstock and Ash Solids

Samples for laboratory chemical analysis include biomass feed, bed bottom ash, bed top ash, and candle filter ash. These samples will be collected and submitted to commercial laboratories for analysis. We will attempt to locate standard methods appropriate for wood solids and wood ash. If procedures specific to wood can not be located, then the analyses for density, moisture content, and heating value, as well as the proximate and ultimate analyses for water, carbon, nitrogen, and sulfur content will be based on ASTM methods designed for coal. Analysis of metals in ash will be by AA or ICAP. Portions of the sampled solids will be stored in identified hermetically sealed containers in CE-CERT's laboratory. The storage is under the responsibility and control of the laboratory manager.

Table 5-1. Standard measurement and calibration methods for the HPR

| Parameter | Measurement Method | Accuracy/Precision | Calibration |
|---|--|--|---|
| Temperature | Type K thermocouple | For 0-1,250 C°: ±2.2 C° or ±0.75% | ASTM E-220 |
| Pressure | Pressure transducers Differential Regular | ±0.2% of span (±2 psi) ^a ±0.5% of span (±5 psi) ^a | Periodic calibration with test gauge against transducer |
| Flow rate (gas) | Orifice plates | Dependent on other measurements ^b ±1.0% ^c | Calibration against other orifice plate meters |
| Flow rate (solid) | Screwfeeder rpm | ±1.0% ^d | gravimetric |
| Gas composition Carbon Non-carbon | Extraction: GC/FIS GC/TCD | ±1000 ppm ^d ±5000 ppm ^d | SCAQMD 25.1 |
| Gas particulates | EPA/CARB Method 501 (isokinetic sampling with a cascade impactor) | ±10% ^e | EPA/CARB Method 501 |
| H ₂ S concentration | Collection in tedlar bag diluted with N ₂ | TBD ^f | NIOSH Sampling Tubes |
| Solids analysis: | | | |
| Proximate: | | | |
| Moisture | ASTM D-3173 ^g | ±0.2-0.3% | ASTM D-3173 |
| Volatile matter | ASTM D-3175 ^g | ±0.2-1.0% | ASTM D-3175 |
| Ash | ASTM D-3174 ^g | ±0.2-0.5% | ASTM-D-3174 |
| Fixed carbon | By difference | | |
| Ultimate | | | |
| Sulfur | ASTM D-3177 ^g | ±0.05-0.1% | ASTM D-3177 |
| C, H | ASTM D-3178 ^g | ±0.3%, ±0.07% | ASTM D-3178 |
| N | ASTM D-3179 ^g | TBD | ASTM D-3179 |
| Ash | ASTM D-3174 ^g | ±0.2-0.5% | ASTM D-3174 |
| Moisture | ASTM D-3176 ^g | ±0.2-0.3% | ASTM D-3176 |
| Oxygen | By difference | | |
| Heating value | Calorimeter | TBD | Calibration |
| Particle sizes | Coulter counter | TBD | Calibration |

^aRosemount catalog.

^bAccuracy of orifice plates depends on accuracy of other measurements.

^cGerand venturi.

^dEngineering estimate; varies depending on compound's concentration compared to detection limit (see Section 3.5).

^eAnderson Samplers, Inc.

^fTBD = To be determined.

^gMethods described for coal; assumed applicable to wood pending confirmation with commercial laboratories.

SECTION 6

HPR DATA REDUCTION, VALIDATION, AND REPORTING

6.1 Data Reporting

Field measurements from the pilot-scale reactor and laboratory analyses will be integrated into the final report. The Principal Investigator will have responsibility for final data reduction and integration of data into the report. Data will be acquired using a data logger for continuous measurements, and through use of data notebooks.

Data tapes or records and field laboratory workbooks will be turned over to the CE-CERT Project Engineer after sampling concludes. The field measurement data will be reduced by staff engineers under the supervision of the CE-CERT Project Engineer and the Acurex Project Manager.

The analytical data (for solid samples) from the laboratories will be supplied to the CE-CERT Project Engineer and reported as quantity of analyte measured per sample unit. The CE-CERT Project Engineer will audit the laboratory results for completeness. The QA Reviewer will also review the laboratory reports.

The CE-CERT Project Engineer will assemble and integrate the analytical data with the reduced field data into the draft final report, which will present measurement results, interpretations, and conclusions. The draft final report will also contain a QA/QC evaluation section in which measurement accuracy, precision, and completeness will be assessed. The QA results will be compared to the project Data Quality Objectives (DQOs). If the DQOs are not met, the report will discuss the resulting impacts, if any, on project objectives. Reports on any corrective action and discussions of outstanding issues and concerns resulting from any external performance audits will also be addressed in the QA/QC section of the report.

6.2 Data Reduction

Table 6-1 summarizes the data reduction methods that will be used to interpret the data from the HPR study. The overall goal of this project is to achieve at least an 80-percent carbon conversion efficiency at a feed flow rate of 50 lb/hr. It is also the objective of this demonstration project to determine the range of flow rates that will yield a carbon conversion within an acceptable range of the carbon conversion goal. Overall and carbon mass balances will provide important tools for making this determination.

Table 6-2 shows sampling points for continuous gas flow data. These include thermocouples and pressure transducers associated with flows into and out of the HPR. Gas flows are calculated based on the pressure drop across an orifice meter as indicated in Table 6-3.

The primary data analysis effort will be the analysis process flow rates and material balances to determine carbon conversion and evaluating kinetics. For each test matrix data set, the measured gas flows in the HPR will be compared with equilibrium predictions. Figure 6-1 shows the planned

comparison of HPR gas flow rates. Gas flow rates in kmol/h will be determined from the gas concentrations and HPR exit flow rate (QHo). The range of HPR exit flow rates will be compared to those predicted by equilibrium.

Figure 6-2 shows the carbon balance analysis for the HPR. The total carbon converted will be calculated from inlet and exit gas and solids compositions and flow rates and compared to equilibrium values. This calculation of net carbon is based on the difference between the carbon content of inlet and exit gas flow rates.

Carbon conversion will be assessed in terms of the ratio of measured carbon to expected carbon. Table 6-4 shows the figures of merit that will be used to assess the carbon conversion in the HPR. The first evaluation, carbon conversion, shows the fraction of the biomass feed that is converted to carbon in the HPR outlet gas. The carbon balance data will also be compared with the carbon content of HPR char in the bottom ash and the filtered particles. The carbon conversion does not rank to what degree equilibrium was achieved. The approach to equilibrium will be rated for total carbon balance as well as in terms of desired products (CO and CO₂).

6.3 Data Validation

Several mechanical and mathematical procedures will be used to ensure that valid results and calculations are achieved. These will be provided in the form of a check list for the operator and analyst. The check list will be used for data review and audits.

Data validation and reduction auditing will be performed at several levels. The Sample Custodian will review and audit the field data sheets for completeness and accuracy by comparing them with previously compiled data. The Principal Investigator and the Acurex Project Manager will also review the reduced field and analytical data for completeness, and will perform audits of selected calculations to ensure data validity. An internal audit by the CE-CERT QA reviewer will be made with the CE-CERT Project Engineer at least once during the test period. The test program identified in this effort is sufficient to ensure that sources of sampling and analysis error will be identified.

Table 6-1. Data reduction objectives for the HPR

| Data Reduction or Calculation | Goal |
|--|----------------------|
| Overall mass balance | ±10% |
| Carbon conversion efficiency | >80% ±5% |
| Carbon conversion to equilibrium CO, CH ₄ , and CO ₂ | >90% ±5% |
| Operating range of flow rates | 50 lb/hr ±x lb/hr |
| Residence time at steady state, $t = m/Q$ | Find range $t \pm z$ |

Table 6-2. Continuous data collection parameters

| PRIMARY DATA - MEASURED VALUES | | | |
|---|---------------|-------------------|--------------|
| Parameter | Symbol | Instrument | Units |
| H ₂ inlet pressure differential | dP3 | PDIT-003 | kPa |
| H ₂ inlet pressure | P2B | PI-002B | kPa |
| CO ₂ inlet pressure differential | dP44 | PDIT-044 | kPa |
| CO ₂ inlet pressure | P42B | PI-042B | kPa |
| CO ₂ inlet temperature | T56 | TE-056 | C |
| CO inlet pressure differential | dP7 | PDIT-007 | kPa |
| CO inlet pressure | P6B | PI-006B | kPa |
| Process N ₂ inlet pressure differential | dP11 | PDIT-011 | kPa |
| Process N ₂ inlet pressure | dP10B | PI-010B | kPa |
| Mixed gas inlet temperature | T24 | TE-024 | C |
| Mixed gas stream pressure | P28 | PT-0028 | kPa |
| Mixed solids feed rate | M850 | SF-850 | rpm |
| Mixed gas post-HX temperature | T14 | TE-014 | C |
| Mixed gas post-heater temperature | T17 | TE-017 | C |
| Reactor outlet, pre-filter temperature | T818 | TE-818 | C |
| Reactor outlet, post-filter temperature | T824 | TE-824 | C |
| Reactor outlet CO ₂ concentration ¹ | SP-825 | NDIR ² | ppm |
| Reactor outlet CO concentration ¹ | SP-825 | NDIR ² | ppm |
| Reactor outlet, post-HX temperature | T827 | TE-827 | C |
| Reactor outlet, post-HX pressure | P823 | PT-823 | kPa |
| Reactor outlet, post-HX pressure differential | dP826 | PDIT-826 | kPa |
| Steam inlet temperature | T503 | TE-503 | C |
| Steam inlet pressure differential | dP506 | PDIT-506 | kPa |
| Steam inlet pressure | P514 | PE-514 | kPa |
| Natural gas inlet (total) temperature | T633 | TE-633 | C |
| Natural gas inlet (total) differential pressure | dP607 | PDIT-607 | kPa |
| Natural gas inlet (total) pressure | P603B | PI-603B | kPa |
| System N ₂ to T-805 differential pressure | dP403 | PDP-403 | kPa |
| System N ₂ to T-805 pressure | P402B | PI-402B | kPa |
| High pressure N ₂ to F-104 differential pressure | dP55 | PDT-055 | kPa |
| High pressure N ₂ to F-104 pressure | P54 | PI-054 | kPa |
| High pressure N ₂ to T-842 pressure | P456B | PI-456B | kPa |
| High pressure N ₂ to F-104 pressure | P459 | PI-459B | kPa |
| Air to burner - differential pressure | dP703 | PDIT-703 | kPa |
| Air to burner - pressure | P702B | PI-702B | kPa |

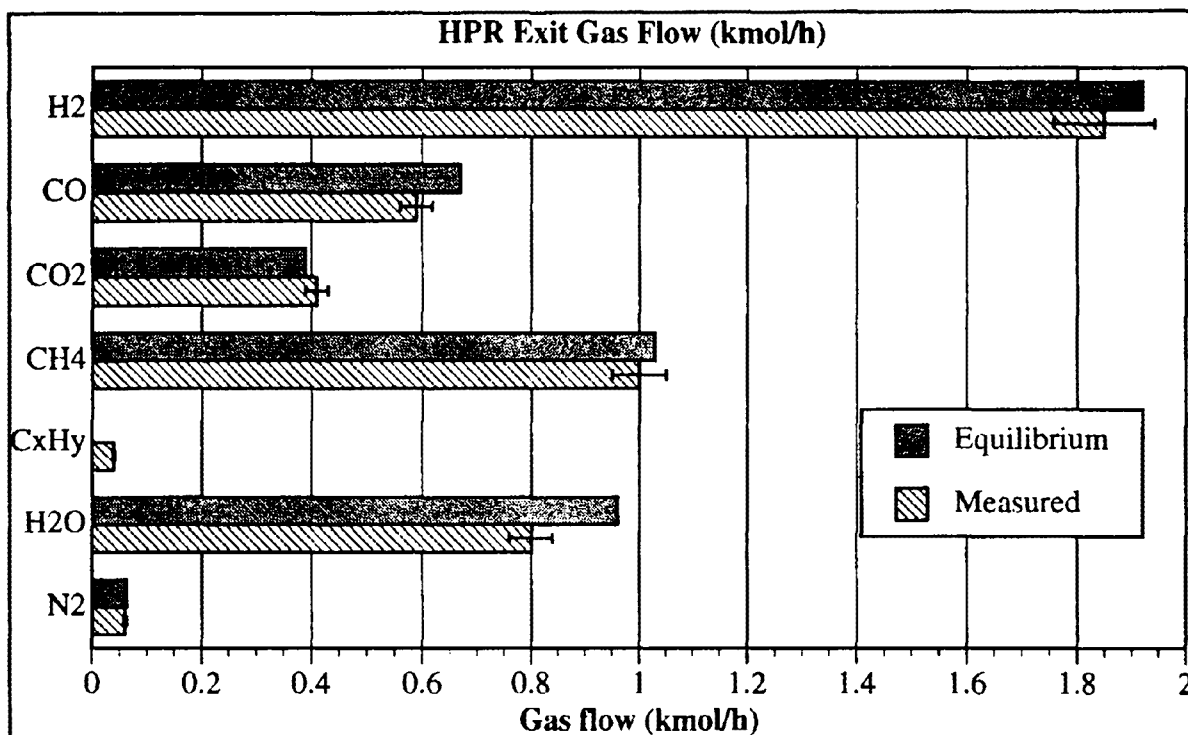
¹ optional

² not yet specified

Table 6-3. Flow rate calculation procedures

| PRIMARY DATA - CALCULATED VALUES | | | |
|----------------------------------|---|---|--|
| Flow rate calculations | Symbol | Units | Formula |
| H ₂ inlet | N-H2IN | kmol/h | $N = KA3 \cdot Y \sqrt{\frac{2 \cdot P2B \cdot dP3}{2.02R(T24 + 273 + dT24)}}$ |
| CO ₂ inlet | N-CO2IN | kmol/h | $N = KA44 \cdot Y \sqrt{\frac{2 \cdot P24B \cdot dP44}{44.01R(T56 + 273)}}$ |
| CO inlet | N-COIN | kmol/h | $N = KA7 \cdot Y \sqrt{\frac{2 \cdot P6B \cdot dP7}{28.01R(T24 + 273 + dT24)}}$ |
| Process N ₂ inlet | N-N2IN | kmol/h | $N = KA11 \cdot Y \sqrt{\frac{2 \cdot P10B \cdot dP11}{28.01R(T24 + 273 + dT24)}}$ |
| Product (post-filter) | N-OUT | kmol/h | $N = KA826 \cdot Y \sqrt{\frac{2(P823 + dP826) \cdot dP826}{8.31R(T827 + 273 + dT827)}}$ |
| Steam inlet | N-STMIN | kmol/h | $N = KA506 \cdot Y \sqrt{\frac{2 \cdot P514 \cdot dP506}{18.02R(T503 + 273)}}$ |
| Air to burner | N-AIR | kmol/h | $N = KA703 \cdot Y \sqrt{\frac{2 \cdot P702B \cdot dP703}{29.0R(T_{amb} + 273)}}$ |
| System N ₂ to T-805 | N-N2SYS | kmol/h | $N = KA403 \cdot Y \sqrt{\frac{2 \cdot P402B \cdot dP403}{28.01R(T_{amb} + 273)}}$ |
| Solids | m-FEED | kg/h | $m = K850 \cdot N850$ |
| Constant values: | KAi | Constant: orifice plate calibration factor and orifice plate area constants for each flow | |
| | Y | Pressure drop correction factor | |
| | R | Universal gas constant = 8.314 m ³ *Pa/mol*K | |
| | M | Molecular weight of gas stream being measured | |
| | H ₂ | 2.02 | |
| | CO | 28.01 | |
| | CO ₂ | 44.01 | |
| | CH ₄ | 16.04 | |
| | H ₂ O | 18.02 | |
| | N ₂ | 28.01 | |
| | Natural gas | 17 | |
| | Air | 29 | |
| | Mixed gas | 8.31 | |
| | T (Kelvin) = T (measured, C) + 273 | | |
| | dT _i = temperature change across orifice | | |

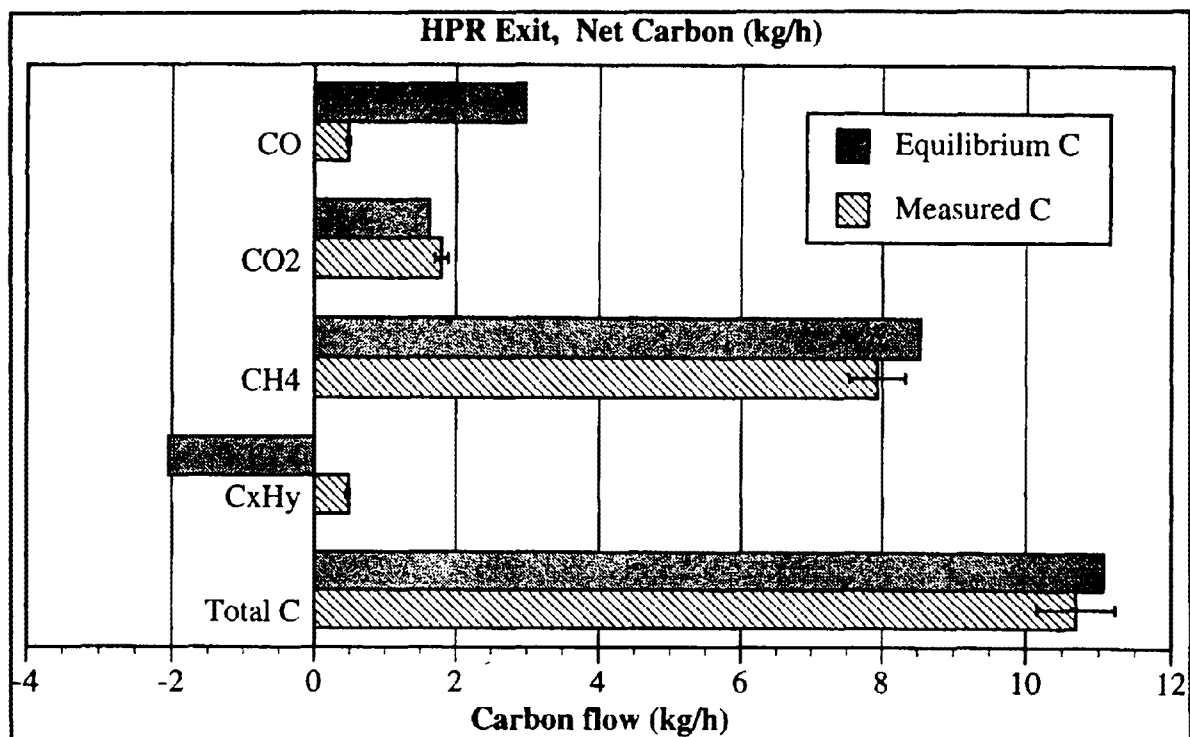
Figure 6-1. Comparison of HPR exit gas compositions



HPR data analysis
Run No. CW1001
Recycle R1
HPR feed gas to biomass ratio (mol/kg)
Recycle **148**
Steam **29**
Natural gas **12**

| Component | HPR out (kmol/h) | |
|-----------|------------------|----------|
| | Equilibrium | Measured |
| N2 | 0.063 | 0.060 |
| H2O | 0.960 | 0.800 |
| CxHy | 0.000 | 0.040 |
| CH4 | 1.030 | 1.000 |
| CO2 | 0.390 | 0.410 |
| CO | 0.670 | 0.590 |
| H2 | 1.920 | 1.850 |
| Total | 5.033 | 4.750 |

Figure 6-2. Carbon balance calculations



HPR Carbon Balance

| | Equilibrium | | Measured | |
|---|-------------|--------|----------|---------|
| | (kmol/h) | (kg C) | (kmol/h) | (kg C) |
| Inlet gas | | | | |
| Total C | 1.168 | 14.03 | 1.15 | 13.8120 |
| CxHy | 0.170 | 2.04 | 0.00 | 0.0000 |
| CH ₄ | 0.320 | 3.84 | 0.30 | 3.6030 |
| CO ₂ | 0.255 | 3.06 | 0.26 | 3.1226 |
| CO | 0.423 | 5.08 | 0.59 | 7.0859 |
| Biomass | | | | |
| | -- | 12 | -- | 12 |
| HPR out | | | | |
| Total C | 2.09 | 25.10 | 2.04 | 24.50 |
| CxHy | 0.00 | 0.00 | 0.04 | 0.48 |
| CH ₄ | 1.03 | 12.37 | 0.96 | 11.53 |
| CO ₂ | 0.39 | 4.68 | 0.41 | 4.92 |
| CO | 0.67 | 8.05 | 0.63 | 7.57 |
| Net Carbon (gas out - gas in) | | | | |
| Total C | 0.922 | 11.07 | 0.89 | 10.69 |
| CxHy | -0.170 | -2.04 | 0.04 | 0.48 |
| CH ₄ | 0.710 | 8.53 | 0.66 | 7.93 |
| CO ₂ | 0.135 | 1.62 | 0.15 | 1.80 |
| CO | 0.247 | 2.97 | 0.04 | 0.48 |
| Char (Carbon flow) | | | | |
| Mass balance | | -0.927 | | -1.311 |
| From ash content | | -- | | -1.500 |
| Carbon conversion | | | | |
| (Net C/biomassC) | | 92.3% | | 89.1% |
| Approach to equilibrium (Measured/Equilibrium) | | | | |
| (Net Carbon) | | | | 96.5% |
| (Net C-CO ₂) | | | | 94.0% |
| (CH ₄) | | | | 93.0% |

Table 6-4. Evaluation of carbon conversion

| Conversion evaluation | Measured quantity | Ideal quantity |
|---|------------------------------|--|
| Carbon conversion | Net carbon HPR outlet | Carbon in biomass feed |
| Carbon conversion relative to equilibrium | Measured carbon conversion | Equilibrium carbon conversion |
| Carbon conversion - CO ₂ relative to equilibrium | Net carbon - CO ₂ | Equilibrium net carbon - CO ₂ |
| Methane production relative to equilibrium | Measured CH ₄ | Equilibrium CH ₄ |

SECTION 7

ERROR ANALYSIS FOR THE HPR

Due to the nature of this demonstration project, highly precise and accurate measurements are not essential to the project's success. The most important measurement parameter for the project is the outlet gas composition and flow rate, which is used to calculate the carbon conversion via a mass balance. Gas compositions measured within 0.1 percent (an accuracy well within the limitations of the GC) are sufficient for the purposes of this project to determine the optimal operating parameters. In measuring gas compositions of the samples, accuracy will be assessed through spike and recovery analyses and the use of 10-percent blanks (1 blank per 9 real samples). For air flow rate, temperature, and pressure measurements, accuracy will be established by calibrating the instruments using ASTM standard methods or a primary standard. Precision is generally measured through the analysis of duplicate samples.

All instruments used will be regularly calibrated to ensure the data's accuracy and validity. Mass balances will also be performed.

CE-CERT will evaluate the magnitude of uncertainty in the values shown in Table 6-1. We will track the propagation of uncertainties of calculated quantities from all of their constituent measured quantities.

The overall uncertainty, U_f , in a function $f(x, y, z)$ can be expressed as:

$$U_f^2 = \left(U_x \frac{\delta f}{\delta x} \right)^2 + \left(U_y \frac{\delta f}{\delta y} \right)^2 + \left(U_z \frac{\delta f}{\delta z} \right)^2 \quad (7-1)$$

As an example, equation (7-1) can be applied to the carbon conversion efficiency, η_c , where:

$$\eta_c = \frac{\dot{m}_{c,out} - \dot{m}_{c,in}}{\dot{m}_{c,biomass}} = \frac{x - y}{z} = f \quad (7-2)$$

To arrive at:

$$U_f^2 = \left(\frac{U_x}{z} \right)^2 + \left(\frac{U_y}{z} \right)^2 + \left(\frac{U_z(x - y)}{z^2} \right)^2 \quad (7-3)$$

and the fractional form:

$$\left(\frac{U_f}{f}\right)^2 = \left(\frac{U_x}{x-y}\right)^2 + \left(\frac{U_y}{x-y}\right)^2 + \left(\frac{U_z}{z}\right)^2 \quad (7-4)$$

Table 7-1 shows the extent of error propagation in η_c . The carbon conversion efficiency is defined as the converted carbon in the HPR divided by the carbon in the biomass feed. Because natural gas and optional CO feed gases are already converted to a carbon certainty gas, these are subtracted from the HPR output gas. Table 7-2 shows the quantities used to calculate η_c . The uncertainty for each quantity will be estimated, with Table 5-1 providing guidelines on their magnitude. The error propagation technique in equation (7-1) will be applied to the quantities in Tables 7-1 and 7-2, with the overall uncertainty in η_c yielded by equation (7-4).

A similar approach will be carried out for mass balance calculations and the other quantities in Table 6-1.

For quantities derived from GC measurements, the overall uncertainty will depend largely upon the uncertainty in the measurement of the mass of each component (denoted m_i or m_k in Table 7-2). The error in m_i or m_k depends on the detection limit for that compound. Determination of the uncertainty in m_s will depend on the stability of the flow rate through the screw conveyor.

Table 7-1. Error propagation for carbon conversion efficiency

| | | | | | | | |
|---|--|--|--|--|-------|---|-----|
| $\eta_c = \frac{\dot{m}_{c,out} - \dot{m}_{c,in}}{\dot{m}_{c,biomass}}$ | | | | | | | |
| $\dot{m}_{c,out} = C_{out}\dot{m}_{out}$ | | $\dot{m}_{c,in} = C_{NG}\dot{m}_{NG} + C_{CO}\dot{m}_{CO}$ | | | | $\dot{m}_{c,biomass} = C_s \frac{m_s}{t}$ | |
| $C_{out} = \frac{\sum C_i m_i}{m_{os}}$ | $\dot{m}_{out} = KA \left(\frac{2M_{out}P\Delta P}{RT_1} \right)^{1/2}$ | $C_{NG} = \frac{\sum C_k m_k}{m_{NGS}}$ | $\dot{m}_{NG} = KA \left(\frac{2M_{NG}P\Delta P}{RT} \right)^{1/2}$ | $C_{CO}\dot{m}_{CO} = C_{CO}KA \left(\frac{2M_{CO}P_1\Delta P}{RT_1} \right)^{1/2}$ | C_s | m_s | t |

Table 7-2. Measurements and calculations for carbon conversion efficiency

| Quantity | Description |
|------------------|---|
| A | Orifice plate area |
| $C_{CO} = 0.429$ | Carbon content of CO |
| C_i | Carbon content of component i of HPR outlet sample |
| C_k | Carbon content of component k of natural gas sample |
| C_{NG} | Carbon content of feed gas |
| C_{out} | Carbon content of HPR gas |
| C_s | Carbon content of solid feed |
| ΔP | Pressure drop across orifice plate |
| K | Orifice plate calibration factor |
| \dot{m}_{CO} | Mass flow rate of CO |
| m_i | Mass of component i of HPR outlet GC sample |
| m_k | Mass of component k of natural gas GC sample |
| \dot{m}_{NG} | Mass flow rate of feed gas |
| \dot{m}_{out} | Mass flow rate of HPR gas |
| m_{os} | Mass of HPR outlet sample into GC |
| m_s | Solid feed mass |
| m_{NGS} | Mass of natural gas sample into GC |

Table 7-2 (continued). Measurements and calculations for carbon conversion efficiency

| Quantity | Description |
|---|--|
| $M_{CO} = 28.01$ | Molecular weight of CO |
| $M_{NG} = \frac{\sum M_k m_k}{m_{NGS}}$ | Molecular weight of feed gas |
| $M_{out} = \frac{\sum M_i m_i}{m_{os}}$ | Molecular weight of HPR gas |
| M_i | Molecular weight of component i of HPR gas |
| M_k | Molecular weight of component k of natural gas |
| P | Pressure |
| $N_{CO} = KAY \sqrt{\frac{2P_1 dP}{M_{CO} RT_1}}$ | CO molar flow rate |
| $P_1 = P_2 + dP$ | Pressure before flow orifice |
| P_2 | Pressure after flow orifice |
| dP | Pressure differential across flow orifice |
| $N_{out} = KA \sqrt{\frac{2\Delta P}{\rho}}$ | HPR gas molar flow rate |
| N_{NG} | Natural gas molar flow rate |
| $R = \frac{8.3143 \text{ m}^3 \cdot \text{Pa}}{\text{g mole} \cdot \text{K}}$ | Universal gas constant |
| $\rho_i = \frac{P_i M}{RT_i}$ | Gas density at conditions P_i and T_i |
| T | Temperature, Kelvin |

Table 7-2 (concluded). Measurements and calculations for carbon conversion efficiency

| Quantity | Description |
|------------------|--|
| $T_1 = T_2 + dT$ | Temperature before flow orifice |
| T_2 | Temperature after flow orifice |
| dT | Temperature differential across flow orifice |
| t | Time |

SECTION 8

PERFORMANCE AND SYSTEM AUDITS

The internal auditing procedures to be used in this project will be implemented by the Principal Investigator. The CE-CERT Project Engineer will be responsible for internal auditing at the data collection level, and the CE-CERT Project Engineer and the QA Reviewer at the data reduction and evaluation level. Monitoring of sampling activities will be performed by the CE-CERT Project Engineer, who has primary responsibility for data quality. The CE-CERT Project Engineer will continually assess the performance of the sampling team members during field testing, and ensure that proper equipment is used as specified in the sampling protocols. This monitoring will extend to performance of on site analyses and to sample preparation, collection, recovery, and packaging. The QA Reviewer will conduct at least one independent audit of this process during the test period and advise the Principal Investigator, the Acurex Project Manager, and the CE-CERT Project Engineer of any issues to be dealt with. The QA Reviewer will audit the data reduction and evaluation process once in the early stages of testing in accordance with a procedure established by the CE-CERT Project Engineer. A second audit will be conducted at the end of the testing as a cross-check on the results.

If external performance audits are scheduled by the AEERL QA Officer (QAO), the facility operators will cooperate fully. In addition, audit samples deemed appropriate by the AEERL QAO will be processed. No performance audits are currently planned.

SECTION 9

CORRECTIVE ACTION

Corrective actions are initiated whenever measurement precision or accuracy deviates from the objectives for each phase of the project. In addition, corrective actions are initiated whenever problems are identified through the internal or external auditing procedures described in Section 8.

Corrective action will be assured by the QA Reviewer after the initial audit, and if needed an additional audit will be scheduled with the Principal Investigator and the CE-CERT Project Engineer. A posteriori correction may be needed at the final audit after data processing review. If this is required, steps for corrections will be agreed upon by the QA Reviewer, the Principal Investigator, and the Acurex Project Manager. After revisions of data analysis are complete the QA reviewer will again audit the results to assure that corrections or inconsistencies are accounted for.

Corrective actions begin with identifying the source of the problem. Potential problems might include failure to adhere to prescribed methods, or equipment malfunction. Such problems are corrected by more intensive staff training, if appropriate, or by equipment repair followed by increased preventive maintenance.

The CE-CERT Project Manager has the primary responsibility for initiating and completing corrective action required for field measurement systems. Problems may be identified by sampling personnel, or by the CE-CERT Project Engineer. If staff training is required, the Principle Investigator is responsible for ensuring it takes place. The QA Reviewer monitors the progress of corrective actions and ensures that they proceed in a timely manner. The Principal Investigator approves all corrective actions, and, if necessary, obtains concurrence from the AEERL Work Assignment Officer and QAO.

FINAL DRAFT

**Evaluation of a Process to Convert
Biomass to Methanol Fuel**

Measurement Plan for Hydrogasifier Performance Testing

March 1999

Prepared for
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SECTION 1

OVERVIEW AND OBJECTIVES

The purpose of this phase of the Hynol project is to demonstrate the feasibility of hydrolyzing biomass feedstocks at high temperature and pressure in the presence of varying simulated recycle gases. The overall goal is to achieve ~~at least 80 percent~~ ^{80%} ~~($\pm 10\%$)~~ carbon conversion efficiency at a feed flow rate of 50 lb/hr. The hydrolysis reactor (HPR) must also be shown to operate with minimal external energy sources, obtaining energy for endothermic reactions from feed stream enthalpy and from exothermic reactions occurring within the reactor. Because no such system has been operated, steady state operation of the HPR has yet to be defined. The data from this study will serve to develop procedures for reactor startup and shutdown, characterize steady state operation, and establish a time interval to reach steady state. The system's sensitivity to operating variables must be determined in order to identify optimal conditions that will maximize carbon conversion efficiency. In addition to these overall objectives, the performance of the high temperature aerosol filter, alkali getters, and pollution equipment will also be evaluated. More details on the project scope and objectives can be found in the Work Plan [1] and the Quality Assurance Plan [2]. The Design Report [3] gives more information on the chemical process and plant layout.

The system to be used in this experiment has been designed at Arcadis Environmental Corporation. The U.S. Environmental Protection Agency (EPA) has funded the project under cooperative agreement CR 824308-01-0.

During operation, the HPR will be fed with biomass in the form of white oak sawdust. Within the gasifier, recycle gases will also be injected, and they will form a fluidized bed with the biomass. In the complete process, the recycle gases will come from a methanol synthesis reactor. However, during the testing of the decoupled HPR, the recycle gases will be simulated with mixed bottled gases and steam in similar proportions to the expected recycle gases. The main objective of the hydrogasification is to convert the carbon in biomass to methane and carbon monoxide. The effluent gas mixture exits the gasifier through a cyclone, where it will pass through a hot gas particulate filter and various heat exchangers before being flared. The Process and Instrumentation Diagram (P&ID) in Appendix A shows the HPR system configuration.

This test plan describes all the measurements and analyses required to conduct the test and assess whether the test objectives are met. The instruments and sensors to be used for measurement of flow rates, chemical composition, pressure, and temperature are described. Analysis methods, calculation methods, and estimated error in measurements and calculations are also included. The test plan also specifies how the numerous data are to be logged, and the type of staffing required to carry out the testing.

A carbon balance will be used to assess carbon conversion efficiency. An energy balance will be performed to assess the energy usage of the system. Continuous measurement of system parameters will help to characterize steady state operating conditions. Various batch analyses for toxic species will be performed to ensure the system operates safely and does not create environmental hazards. Suspended particulate concentrations will be measured to assess filter performance. The rate of erosion and other measures of wear on system materials will also be evaluated. The following sections describe the testing approach that will be taken.

SECTION 2

CARBON CONVERSION EFFICIENCY

A carbon balance on the HPR system will be used to calculate the carbon conversion efficiency, η_c . At steady state, a carbon balance should reveal that the amount of carbon leaving the system (as gas, char, and ash) is equal to the amount of carbon entering the system (as gas and biomass). The relation used for the carbon conversion efficiency calculation will be:

$$\eta_c = \frac{\dot{m}_{\text{gaseous C, out}} - \dot{m}_{\text{gaseous C, in}}}{\dot{m}_{\text{biomass C}}} \quad (2-1)$$

where \dot{m} denotes mass flow rate.

This requires knowledge of the amount of carbon entering and leaving the HPR. Therefore, flow rates and compositions of the biomass feed, input gases, and output gases must be measured. To complete the carbon balance, the flow rate and composition of the reactor char and filter ash also must be measured.

2.1 BIOMASS

The biomass is stored in a large bin with a 2400 lb capacity (2-3 days of testing). The biomass is weighed in the storage bin with four load cells, one under each leg. Each load cell has a manufactured accuracy of 0.1% with a combined accuracy of +/- 40 lb. This accuracy accounts for a theoretical uncertainty in the biomass input of 6% (assuming a 12-hour sample duration). The storage bin/weighing system schematic is shown in the P&ID. The system uncertainty will be estimated with a five point calibration at CE-CERT using water to obtain 1k, 1.5k, 2k, and 2.5k distributed loads. The biomass enters the reactor, R101, through a pressurized lock-hopper system that is controlled by a level sensor. The biomass feed system is completely automatic and requires no operator control except for occasional bridging problems in the storage bin.

The amount of carbon in the biomass will be determined at Desert Analytics in Tucson, Arizona, using the American Society of Testing and Materials (ASTM) Methods D-3175/D-1102. During a test period, a series of representative samples of biomass will be analyzed. The exact number of samples will be determined at the time of the testing after analyses of at least eight initial samples. Carbon composition throughout the biomass pile is not expected to vary by more than $\pm 0.5\%$. When coupled with the uncertainty in the analytical method and the moisture uniformity, which will be approximately 1.5% (absolute), the uncertainty in the carbon composition of the biomass will be about 3%.

1. The total uncertainty in the amount of carbon entering the HPR as biomass will be approximately 3.4% (relative). An example error analysis is shown in Appendix B for illustration of the methods to be used.

2.2 MAKE-UP GASES (INPUT GASES)

The input gases simulate the recycle stream from the methanol synthesis reactor in the integrated Hynol system. Of these, recycled CO, CO₂, steam, and CH₄ are important to the carbon conversion efficiency. CO will be provided in a compressed gas trailer from Air Products Corp. (with an NIST traceable certificate). The CO₂ will be supplied through a line from Bourns, Inc., which is adjacent to CE-CERT. Both CO and CO₂ will be periodically checked for purity using the continuous gas analyzers, described in Section 3. The CH₄ will be provided through public natural gas lines. Since natural gas is not completely composed of CH₄, the natural gas

composition will be analyzed for C_2H_6 , CO_2 , and N_2 from an integrated sample, at least once during each test period. A gas chromatograph with thermal conductivity detector (GC/TCD) at the Inchscape Laboratories will be used for this purpose. The method to be used for this analysis is EPA Method 18.

Procedures for measurements of parameters such as gas flow, temperature, pressure, and measurement uncertainty will be taken from the Performance Test Codes (PTC) published by ASME.

Flow rates of input gases will be measured by orifice flow meters [4] using methods outlined in ASME P.C. 19.5. The correlation used to calculate flow rate through an orifice meter is:

$$Q = C \sqrt{\frac{M \cdot P \cdot dP}{T}} \quad (2-2)$$

where Q is the flow rate, M is the molecular weight of the gas, P is the pressure, dP is the pressure differential across the orifice plate, and T is the absolute temperature. C is the orifice constant, determined by calibration with known gas flow rates (obtained from factory certification).

Temperatures will be measured (using the methods outlined in ASME P.C. 19.3) with Type K thermocouples, which have a precision of $\pm 10^\circ C$. Pressure will be measured (ASME P.C. 19.2) with pressure transducers, which have a precision of approximately ± 1.5 psi. Pressure differentials will be measured by differential pressure transmitters, which have a precision of ± 0.0022 psi. Taking these uncertainties (found by the methods outlined in ASME P.C. 19.1) into account, the total relative uncertainty in a flow rate measurement will be about $\pm 0.4\%$. The uncertainty in the gaseous carbon input rate will be 0.4% for input gases. Illustrative calculations of these errors are shown in Appendix B.

The accuracy of the temperature and pressure sensors will be established following standard procedures, with references to primary standards. For temperature, the thermocouples will be calibrated over a range of interest using immersion in boiling fluids of known boiling point or freezing point. Pressure sensors will be calibrated in a dead weight tester from 0 – 1000 psi.

2.3 OUTPUT GASES (GASIFIER EFFLUENT)

Gas samples will be collected in pre-cleaned, evacuated stainless steel sample canisters. These samples will then be analyzed for CH_4 , CO_2 , CO , and non-methane organic compounds (NMOC), using GC/TCD analyses at Inchscape Laboratories. The method used for this GC/TCD analysis will be EPA Method 18. Additional analyses, important to the energy and material balances, will also be performed on the canister samples. These analyses are described in Section 3.

The flow rate of the effluent (following moisture removal) will be measured in the same way as that of the input gases. Combining the uncertainties resulting from carbon concentration measurements and flow rates, the relative uncertainty in the carbon output rate will be about $\pm 1\%$.

2.4 CHAR AND BOTTOM FILTER ASH

Char will be collected from the HPR bottom lockhopper and weighed once every hour. This will establish an hourly flow rate. Because the char from the HPR will contain sand and kaolinite, the mass of actual wood char will be determined by subtracting the hourly sand and kaolinite feed rates from the char output rate.

Once steady state is reached, the filter ash will be emptied and discarded. The filter ash accumulated from then on will represent an average of the filter ash during the steady state operation. The Uncertainty in the ash flow rate and carbon content is estimated to be small in comparison to the uncertainties in other flow streams. If this assumption is proven in operation, these uncertainties will be neglected in the analysis.

The composition of the char from the HPR and the ash from the filter will be analyzed at Desert Analytics and Core Laboratories Petroleum. The carbon contents will be analyzed using ASTM Methods D-3175/D1102.

2.5 CARBON CONVERSION EFFICIENCY CALCULATION

Simulations of the gasification process have been performed at the EPA National Risk Management Research laboratory [5]. Table 1 shows estimated flow rates and flow rate errors for the process streams containing carbon.

Table 1. Predicted flow rates for carbon-containing process streams.

| Stream | Flow rate | Carbon flow rate | Carbon flow rate uncertainty [*] |
|------------------------|--------------|------------------|---|
| | (kmol/h) | (kmol/h) | (kmol/h) |
| Entering | | | |
| Biomass | 22.7 (kg/h) | 0.8210 | 0.047 |
| CO | 0.1612 | 0.1612 | 0.00067 |
| CO ₂ | 0.0983 | 0.0983 | 0.0004 |
| CH ₄ | 0.0449 | 0.0449 | 0.0002 |
| Exiting | | | |
| Effluent ^{**} | 3.056 | 1.0575 | 0.0004 |
| Ash | 1.564 (kg/h) | 0.1303 | |

^{*} Calculations of these values are shown in Appendix B.

^{**} Composition of effluent is shown in Appendix B.

Using these values, an HPR carbon conversion efficiency is calculated as:

$$\eta_c = \frac{1.0575 - (0.1612 + 0.0983 + 0.0449)}{0.821} = 0.917$$

Although 91.7% carbon conversion efficiency is not necessarily expected to be achieved in actual operation, the method of calculation will remain the same. In the case of less efficient carbon conversion, the excess carbon would exit as char from the bottom of the HPR, and as particulate carbon (ash) collected on the outflow filter. The latter is expected to be small compared with the flow of bottom char. Using the predicted values in the error analysis specified in Appendix B, the uncertainty in η_c is expected to be $\pm 5.6\%$ in carbon conversion.

SECTION 3

SAMPLING METHODOLOGY

Acquisition of samples is required for gas and aerosol particle carbon analysis of effluents from the HPR system. To accomplish this task, special techniques are required. The methods to be used for gas and particulate sampling are described in the following paragraphs.

To obtain samples of effluent, the system pressure must be reduced from 29 atm to approximately 1 atm before passing through moisture condensers and the gas analyzers. Extracted samples also must be cooled from operating temperatures of the HPR system to a level above saturation for effluent water vapor, but a level where samples can be handled safely. After particle removal at elevated temperature to prevent condensation on the filter, the gas stream must then be cooled further to remove the water vapor, and then passed into the gas analyzers.

The planned pre-filter sampling configuration is shown in Figure 1. Sample flow through this system will be measured using a calibrated dry gas meter. This sampling tap will be located at the top of the exit gas cyclone. Two additional sampling taps will be installed, for collection of samples downstream of the process filter. The sampling configurations at these taps are described in later sections of this plan. Most samples will be taken from this location because of the much lower effluent temperature. Isokinetic sampling will be attempted at both locations. This is not critical, however, because of the fact that the particles present are expected to be in the sub-micrometer size range, and will be at low concentration. The hot gas filter is predicted to have a collection efficiency of over 99%; thus, the particles that penetrate the filter should be small enough to follow the gas flow into the sampling stream. The low concentrations of particles will introduce a small potential for uncertainty in the carbon balance calculations. For practical purposes, the small concentrations will add only a small uncertainty in the evaluations of the filter performance by means of collection efficiency estimates.

The sampling filters will collect samples of particles in the stream. The concentration of these particles should be small if the HPR and hot gas filter operate as expected. With the gas sampling measurement system, the mass concentration of particles in the stream can be calculated from the mass collected in the filter, and the amount of tars collected in the knockout section over a time period. When particulate samples are not being taken, the filter and tar knockout section will serve primarily to condition the gas sample entering the continuous analyzers.

The gas stream will periodically be analyzed for hydrogen sulfide content, as part of the pollution assessment, to be described in more detail in Section 4.2.

Gravimetric analyses of the impinger solutions will be used to determine the moisture content of the effluent according to EPA Method 4. The method has an accuracy of $\pm 2\%$. The impingers are used to remove moisture from the effluent gas, so as to condition it before passing through the continuous analyzers. Some samples of this water will be analyzed at Core Laboratories Petroleum for trace constituents, using EPA Method 8240 for condensed organics, and EPA Method 8270 for extractable organics.

The carbon content of the HPR effluent will be measured by continuous gas analyzers. These measurements will be used to determine and characterize achievement of steady state. Three nondispersive infrared analyzers will detect the concentrations of CH_4 , CO , and CO_2 in the effluent, with approximately $\pm 5\%$ accuracy. The method of calibration will be South Coast Air Quality Management District Method 100.1. Calibration will employ bottled gas standard mixtures whose composition is traceable to primary standard mixtures. The bottled gas mixtures will be obtained from Scott Specialty Gases.

Canister samples will be analyzed for carbon-containing compounds, as specified in Section 2.3. The samples will also be analyzed for H₂ using the GC/TCD supplied by CE-CERT. These measurements will be used for the energy balance. Trace contaminants will also be measured from the canister samples and the condensate traps using GC/MS analysis from Performance Analytical laboratories.

SECTION 4

SUPPLEMENTAL ANALYSES

In addition to the analysis of carbon content, various other analyses will be performed on the biomass and the ash by BC Laboratories. Table 2 lists the analyses and the methods that will be used. During the first day of the first test period, samples of biomass will be gravimetrically analyzed for moisture on site three times per hour. The purpose of the frequency of this analysis is to determine the variability of moisture in the biomass throughout the stock, and throughout the day. The frequency of moisture analyses will be adjusted in subsequent testing according to the amount of variability observed. Alkali getter serves to neutralize the alkaline ash from the wood. Its performance will be determined by measuring the amount of alkali getting agent and alkali metals in ash and collected filter particles.

Table 2. Additional, non-critical analyses to be performed on biomass and ash.

| | Analysis | Method |
|-----------------|---|---|
| Biomass only | Moisture | ASTM E-871 |
| | H ₂ , O ₂ , Total Nitrogen, Total Sulfur | AOAC 972.43 |
| | Gross Heating Value | ASTM D-240 |
| Ash only | High molecular weight hydrocarbons, pollutants and potentially toxic organics | EPA 8270 |
| Biomass and Ash | Na, K | Flame atomic absorption |
| | Al, Be, Cd, Ca, Cr, Fe, Mg, Mn, Ni, K, N, V, Zn | EPA 6010 |
| | Volatiles | ASTM D-3175 |
| | Ash | ASTM D-1102 |
| | Fixed Carbon | Difference between residues from the volatiles test and the ash test. |

4.1 STEADY-STATE CHARACTERIZATION

Steady state operation will be determined through monitoring continuous process measurements such as fluidized bed height, temperature, pressure, pressure differentials, and effluent carbon content. The data collected by the continuous gas analyzers will be used to characterize the gaseous output at steady state, in addition to calculating the carbon conversion efficiency. The temperatures, pressures, and pressure differentials at both critical and non-critical locations will be continuously monitored in order to characterize steady state. The locations of the instruments are specified in the P&ID in Appendix A.

4.2 POLLUTION CONTROL

The char and ash analyses for metals and potentially toxic organics, specified in Table 2, will be part of the pollution assessment. These analyses apply to HPR char and filter ash. The particulates collected in the sampling filters will be analyzed for potentially toxic organics and pollutants by EPA Method 8270 at Core Laboratories Petroleum. The analyses of biomass, char, ash, and effluent for sulfur-containing compounds will also serve this purpose. The sulfur content of the effluent will be measured using a Sensidyne H₂S detector tube.

4.3 FILTER PERFORMANCE

Filter performance will be determined by measuring particle loading of the effluent before and after the filter, mass and composition of filtered particles. The pre-filter sampling line is located at the top of the HPR, with the probe extending down through the tube right above the cyclone. The schematic of the sampling configuration is shown in Figure 1. An additional post-filter sampling tap is installed after the hot gas particulate filter but before the heat exchangers. This sampling system is shown in Figure 2. The sampling systems will be used for particulate loading measurements, as well as for determination of condensable tars and composition of effluent gases. There is some question as to whether particulates will fall out of the effluent stream while passing through the many turns in the heat exchangers. Therefore, we have chosen to sample the effluent before the heat exchangers as a representation of the post-filter particulate loading. This sampling point will provide a precise measurement of particulates than the sampling point before the final heat exchanger. In both pre- and post-filter sampling lines the filter will collect particulates, equilibrated to <50% humidity, and then will be weighed. The difference in amount of particulates collected at pre- and post-filter sites will be used to assess filter performance. The moisture content of the gas stream will also be analyzed before the filter using the hand-held digital hygrometer.

Isokinetic sampling from the top of the HPR will be difficult because the flow leaving the cyclone will be extremely turbulent. However, a quasi-isokinetic sampling will be attempted at this location by sampling the gas at the top of the reactor at the same sample nozzle velocity as the velocity through the exit stream of the HPR.

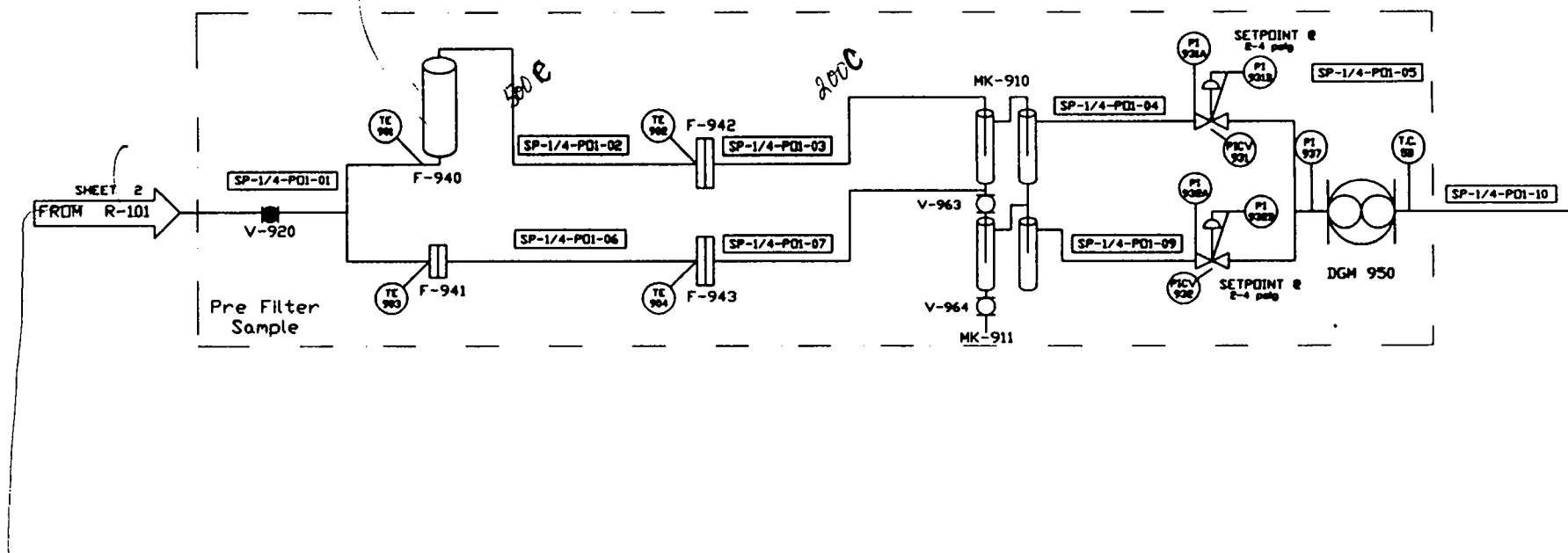


Figure 1. Pre-filter sampling configuration.
Valves denoted by "R" are regulating valves. All others are ball valves.

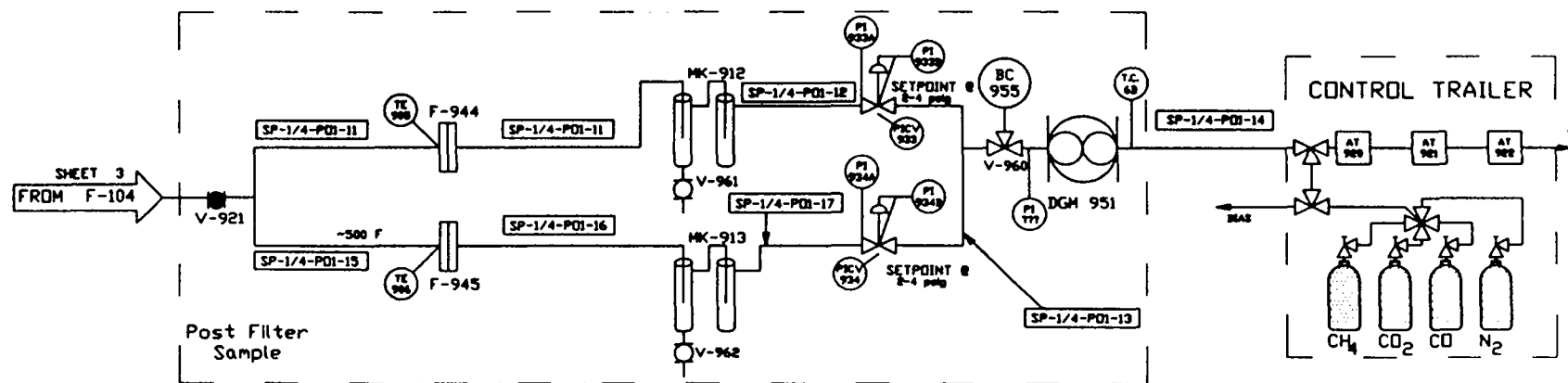


Figure 2. Post-filter particulate sampling configuration.
Valve denoted by "R" is a regulating valve. All others are ball valves.

SECTION 5

ENERGY ANALYSIS

An energy balance will be used to determine the energy usage of the system. Ideally, the HPR-Methanol synthesis system should operate without any additional energy input other than the process stream enthalpies and exothermic reactions within the reactor system. An energy balance of the HPR requires that the flow rates, composition, and enthalpy of each process stream be known.

The method of calculation will be:

$$\sum_{out}(\dot{m}h) - \sum_{in}(\dot{m}h) = \text{enthalpy difference} \quad (5-1)$$

where \dot{m} is the mass flow rate, h is the specific enthalpy of a species, and Σ denotes the sum over the total species entering or leaving the system. Enthalpies are found in the thermodynamic literature, and flow rates are measured. Estimated heat losses can be calculated from the thermal properties of the gases and solids flow, the flow rates, and the thermophysical properties of the vessels, piping, etc.

To calculate flow stream enthalpies, flow rates and temperatures need to be measured. Enthalpy values at the measured temperatures will then be estimated from data in enthalpy tables taken from literature.

5.1 ENERGY RELATED MEASUREMENTS

Biomass feed rate will be measured as specified in Section 2.1. The enthalpy of the biomass is specified in Appendix C.

The method of flow rate measurement for the input gases and effluent is mentioned in Section 2.2. The Type K thermocouples to be used for temperature measurements are also described in that section. Literature enthalpy values for the input gases are shown in Appendix C.

Because the effluent will be a mixture of different gases, the composition of the gas will be analyzed as noted above. Once every species in the effluent has been characterized, the enthalpy of the stream will be determined by summing the enthalpies of the components.

The method of ash flow rate measurement was described in Section 2.4. A literature-based enthalpy value for ash is shown in Appendix C.

5.2 ENERGY BALANCE CALCULATION

The energy balance, in its expanded form, is:

$$\text{enthalpy difference} = [(\dot{m}h)_{\text{effluent}} + (\dot{m}h)_{\text{ash}}] - [(\dot{m}h)_{\text{biomass}} + (\dot{m}h)_{\text{H}_2, \text{in}} + (\dot{m}h)_{\text{N}_2, \text{in}} + (\dot{m}h)_{\text{CO, in}} + (\dot{m}h)_{\text{CO}_2, \text{in}} + (\dot{m}h)_{\text{CH}_4, \text{in}} + (\dot{m}h)_{\text{H}_2\text{O, in}}] \quad (5-2)$$

Table 3 specifies the flow rates that have been calculated for each stream during simulations. The table also shows the flow rate uncertainties, which are needed to conduct an error analysis of the energy balance.

Table 3. Predicted flow rates and flow rate uncertainties for process streams.

| Stream | Flow rate | Flow rate uncertainty |
|------------------|------------------|------------------------------|
| | (kmol/h) | (kmol/h) |
| Entering | | |
| biomass | 22.7 (kg/h) | 0.45 (kg/h) |
| CO | 0.1612 | 0.0007 |
| CO ₂ | 0.0983 | 0.0004 |
| CH ₄ | 0.0449 | 0.0002 |
| H ₂ | 1.771 | 0.0074 |
| N ₂ | .1711 | 0.0007 |
| H ₂ O | 0.2859 | 0.0012 |
| Exiting | | |
| effluent | 3.056 | 0.0062 |
| ash | 1.564 (kg/h) | 0.1 (kg/h) |

* Calculations of these values are shown in Appendix B.

** Effluent composition is specified in Appendix B.

When the flow rates and enthalpies from Appendix C are substituted,

$$\text{enthalpy difference} = -106 \pm 836 \text{ kJ/h.}$$

This enthalpy difference from the illustrative calculations in Appendix C is approximately 0.3% of the enthalpy entering and exiting the reactor, and is attributable to predicted instrumental measurement errors and uncertainties in calculated enthalpies of the gases and solids, including operating temperature variability. The calculated uncertainty of 836 kJ/h represents approximately 0.4% of the enthalpy accounted for. The reactor is assumed for the calculation to be operating adiabatic, excluding work and heat loss from equipment and flow. Table C-1 in Appendix C shows the parameters necessary for the calculation process.

SECTION 6

TEST PLAN AND DATA MANAGEMENT

6.1 OPERATING RANGE

While the first test sequence will serve to demonstrate achievement of steady state and explore steady state vs. transient conditions, the second sequence will be used to determine the carbon conversion and the energy balance for steady state conditions and the nominal operating temperature and pressure expected for the system. The third test will be used to confirm the carbon conversion and energy balance, and to investigate the sensitivity of the process to variables including reactor pressure and temperature. Pending the success of the first test, the exact conditions for the next two sequences will be specified.

6.2 MEASUREMENT FREQUENCY

Process measurements will be taken at regular intervals. Table 4 shows the frequency of measurements to be taken for each test period. Each test period will last three to five days, depending on achievement of steady state.

Table 4. Frequency of measurements.

| Measurement | Frequency |
|-------------------------------------|--|
| Biomass analysis | 1 per test |
| On-site biomass moisture analysis | every 20 minutes (first day) |
| Ash weighing | hourly |
| Ash analysis | 1 per test (three samples from different days) |
| Pre-reactor | |
| Natural gas analysis | 1 per test |
| Input flow rates | every 10 seconds |
| Pre-filter | |
| Particulates | 2 per test (two samples each time) |
| Moisture | 2 per test (two samples each time) |
| Post-filter | |
| Continuous gas analysis | every 10 seconds |
| Effluent flow rate | every 10 seconds |
| Particulates | 2 per test (two samples each time) |
| Particulate – pollutants and toxics | 1 per test |
| Moisture | 2 per test (two samples each time) |
| Moisture - trace constituents | 1 per test |
| H ₂ S | 2 per test (two samples each time) |
| Sample canister GC/TCD analysis | 2 per test (two samples each time) |
| Sample canister GC/MS analysis | 1 per test |
| System parameters | every 60 seconds |
| Filter candle analysis | 1 per test |
| Materials analysis | 1 per test |

6.3 MEASUREMENT SCHEDULE

Tentatively, the testing is scheduled to start in Fall of 1998. Preliminary operational tests should start in Spring, 1999. The first test period should take place in June or July, 1999, with data analysis following. The next two tests should take place in August and September, 1999, respectively.

6.4 DATA LOGGING

Table 5 lists the instruments whose data will be logged directly onto a computer with a data logging program. The P&ID in Appendix A shows where the instruments are located. All other data will be logged by the person performing the measurement.

Table 5. Instruments directly connected to computer data logging device.

| Type of Instrument | Tag Numbers |
|---|---|
| Pressure Differential Indicating Transmitter (PDIT) | 003, 007, 011, 044, 403, 506, 607, 613, 614, 615, 616, 656, 703, 816, 823 |
| Pressure Differential Transmitter (PDT) | 055 |
| Pressure Indicating Transmitter (PIT) | 822 |
| Pressure Transmitter (PT) | 028, 030, 804, 807, 823, 836, 847 |
| Thermocouple (TE) | 014, 017, 020, 024, 025, 028, 633, 808, 809, 810, 811, 812, 813, 814, 815, 818, 824, 825, 826, 827, 828, 831, 841 |
| Temperature Indicating Controller (TIC) | 017 |
| Pressure switch high/high (PSHH) | 027, 030, 836, 853 |
| Pressure switch high (PSH) | 631, 847 |
| Pressure switch low/low (PSLL) | 411 |
| Pressure switch low (PSL) | 057, 411, 631, 715, 847 |
| Temperature switch high/high (TSHH) | 020, 809, 810 |
| Temperature switch high (TSH) | 025, 814, 841 |
| Flow switch, low (FSL) | 011 |
| Continuous analyzers | for CO, CO ₂ and CH ₄ |

6.5 STAFFING

Because the process will be operating 24 hours a day once it is started, there will need to be staff on site at all times. We plan to organize in two 12-hour shifts. This staff will need to ensure that the process is operating correctly, and they will need to perform sampling and weighing. It is estimated that a staff of three people may be needed on-site during the first shift of the first test. The second and third shifts will fall back to two people per shift. After verifying that the plant is operating as planned, the staff can be reduced to two people for all shifts in the second and third test periods. The two staff members will include a supervisor and a process operation technician.

The supervisors need to have full knowledge of how the plant functions and what the test objectives are, so as to ensure the proper functioning toward achieving those objectives. They need to be able to analyze the data as it is processed and suggest corrections or modifications as needed. The sampling technicians need to have knowledge of all the sampling and on-site analysis methods, and make sure that they are carried out with accuracy and precision. The process operation technicians need to know how the input and output streams function, how the vessels function, and how to verify that the system is functioning appropriately. They must also have the ability to fix or adjust any of the equipment on site.

Prior to proceeding with the tests, all staff will be trained to have knowledge of the overall HPR system operation and will be checked out on the specific equipment in the process, as well as the control system for the HPR.

SECTION 7

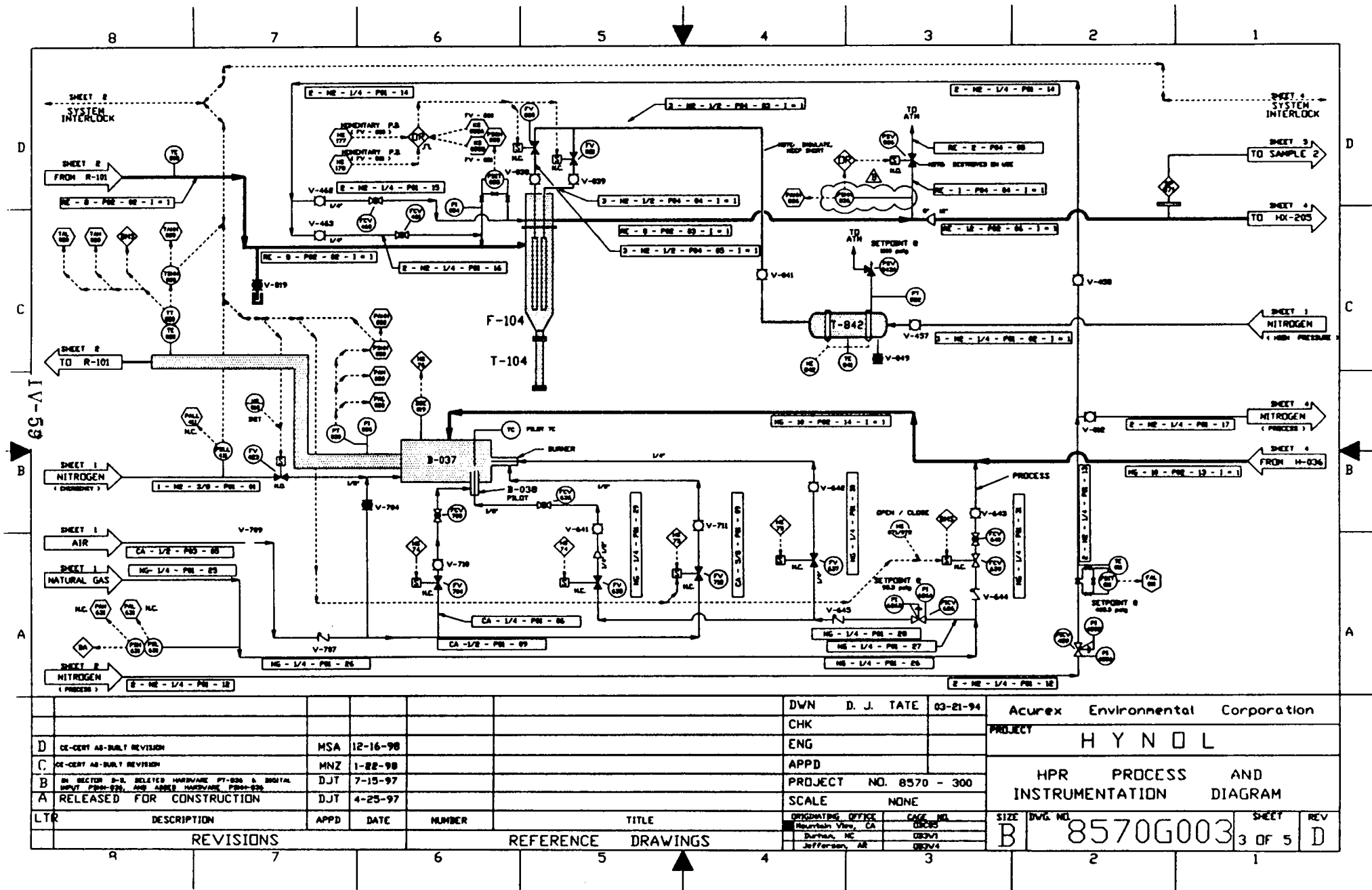
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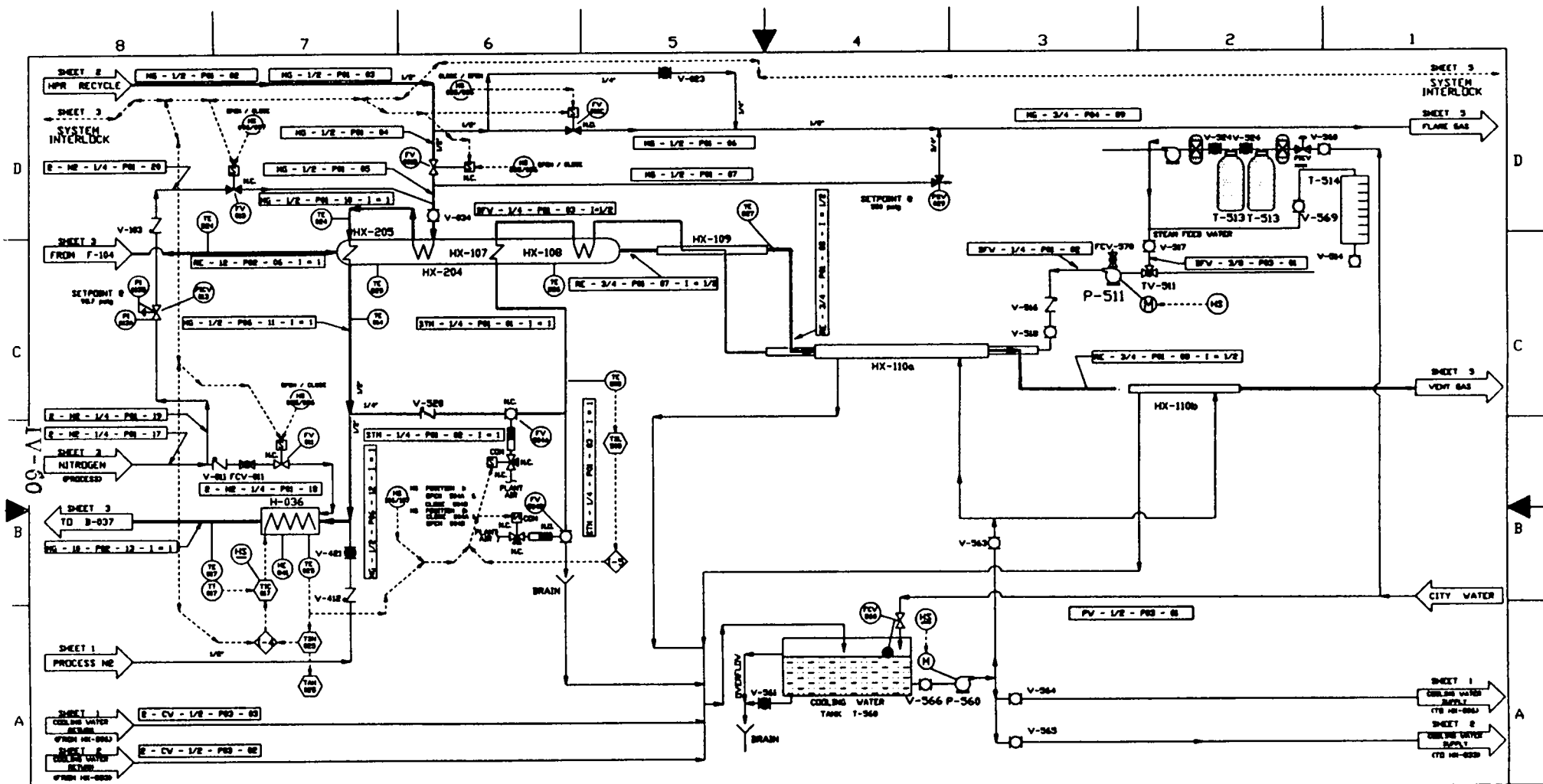
- [1] CE-CERT - *Evaluation of a Process to Convert Biomass to Methanol Fuel - Work Plan*, Univ. of CA, Riverside, 1995.
- [2] CE-CERT, - *Evaluation of a Process to Convert Biomass to Methanol Fuel - Quality Assurance Plan*, Univ. of CA, Riverside, 1995.
- [3] CE-CERT, - *Evaluation of a Process to Convert Biomass to Methanol Fuel - Quality Assurance Plan*, Univ. of CA, Riverside, 1995.
- [4] American Society of Materials Engineering. P.C. 19.5 Application, Part II of Fluid Meters.
- [5] Letter from Robert H. Borgwardt, Project Officer, Atmospheric Protection Branch, Environmental Protection Agency, to Dr. Joseph Norbeck, Director, Center of Environmental Research and Technology, Bourns College of Engineering, University of California, Riverside. February 3, 1997.

Appendix A - P&ID

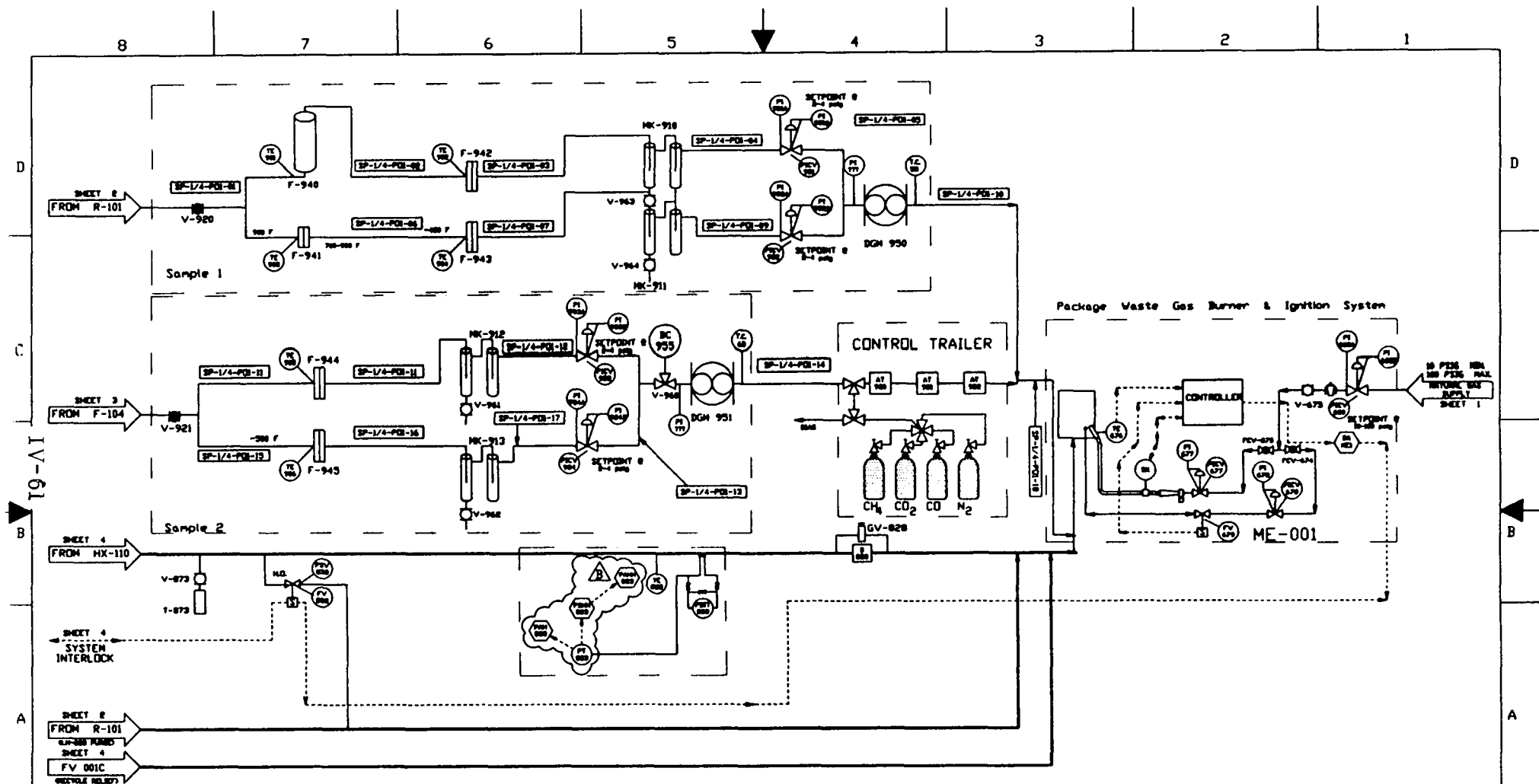
Notation

| | |
|------|-----------------------------------|
| TE | Thermocouple |
| PI | Pressure indicator |
| PT | Pressure transmitter |
| PDIT | Pressure differential transmitter |

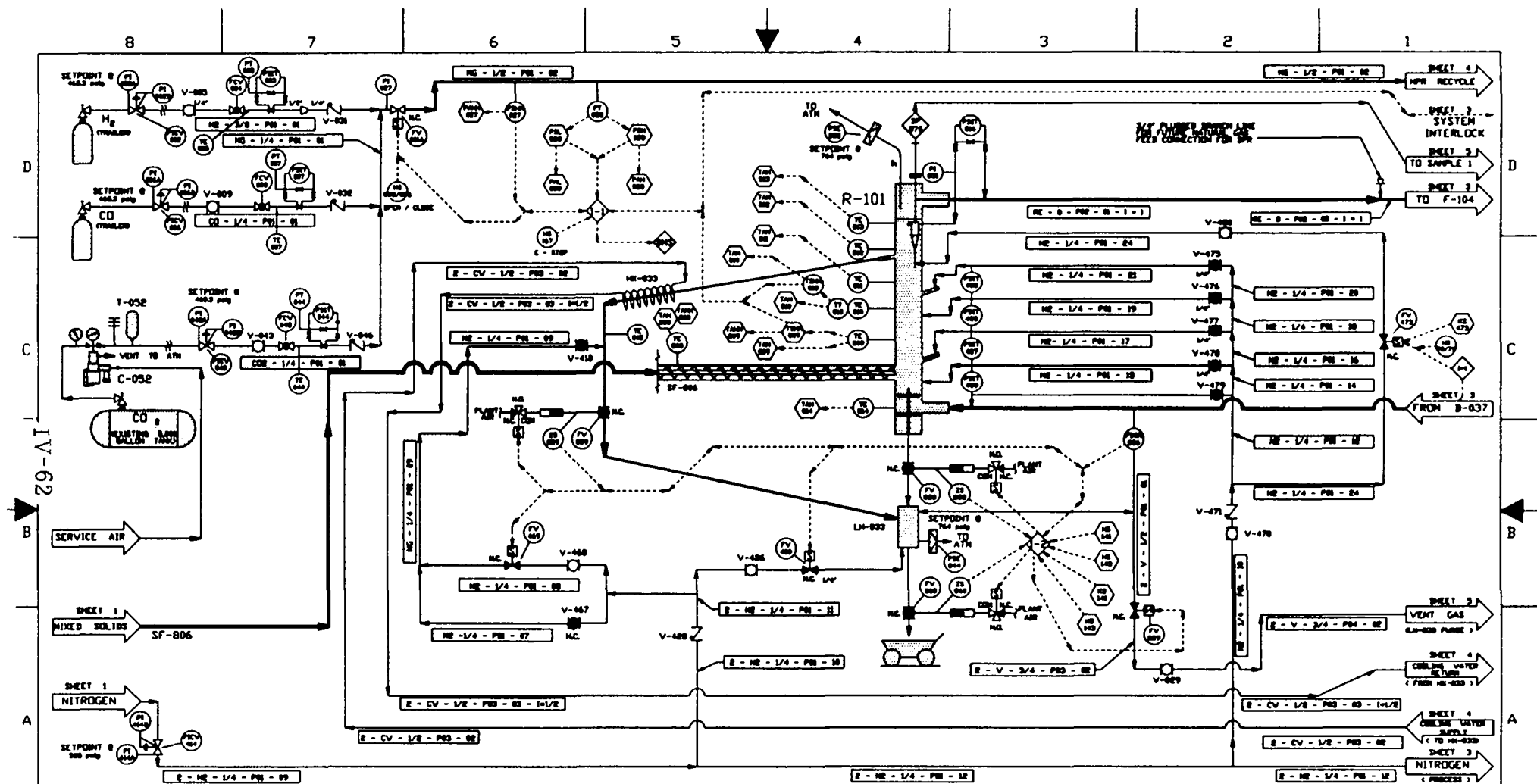




| | | | | | | | | | | | |
|-----|---|-------|----------|--------|--------------------|------------------------|------------|----------|---|--------|-----|
| | | | | | | DWN | B. J. TATE | 03-21-94 | Acurex Environmental Corporation | | |
| | | | | | | CHK | | | PROJECT | | |
| D | CE-CERT AS-BUILT REVISION | MSA | 12-16-98 | | | ENG | | | H Y N O L | | |
| C | CE-CERT AS BUILT REVISION | MW/ZK | 1-22-98 | | | APPD | | | HPR PROCESS AND INSTRUMENTATION DIAGRAM | | |
| B | IN SECTOR B-C, 3, 4, DELETED P-001-002 & P-001-003, AND ADDED P-001-002 & P-001-003 | DJT | 7-15-97 | | | PROJECT NO. 8570 - 300 | | | | | |
| A | RELEASED FOR CONSTRUCTION | DJT | 4-25-97 | | | SCALE NONE | | | | | |
| LTR | DESCRIPTION | APPD | DATE | NUMBER | TITLE | ORIGINATING OFFICE | CAGE NO. | SIZE | BVG NO. | SHEET | REV |
| | REVISIONS | | | | REFERENCE DRAWINGS | Chapman, VA, CA | 08CPS | B | 8570G003 | 4 of 5 | D |
| | | | | | | Barham, NC | 08BVI | | | | |
| | | | | | | Jefferson, AR | 08SV4 | | | | |
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| | | | | DWN | D. J. TATE | 03-21-94 | Acurex / CE-CERT | | | |
| | | | | CHK | | | PROJECT | | | |
| D CE-CERT AS-BUILT REVISION | | | | ENG | | | H Y N O L | | | |
| A CE-CERT AS-BUILT REVISION | | | | APPD | | | HPR PROCESS AND INSTRUMENTATION DIAGRAM | | | |
| B IN SECTOR P-2, ISOLATED HARDWARE PT-026 & INITIAL INPUT P200-026, AND ARMED HARDWARE P200-026 | | | | PROJECT | NO. 8570 - 300 | | | | | |
| A RELEASED FOR CONSTRUCTION | | | | SCALE | NONE | | | | | |
| LTR | | | | OPERATING OFFICE | DATE | | | | | |
| | | | | Mountain View, CA | 03/21/94 | | | | | |
| | | | | Burton, NC | 03/21/94 | | | | | |
| | | | | Jefferson, AR | 03/21/94 | | | | | |
| REVISIONS | | | | REFERENCE DRAWINGS | | | SIZE | SWG | NO. | SHEET |
| | | | | | | | B | | | 5 of 5 |
| | | | | | | | 8570G003 | | | |
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| | | | | DVN | D. J. TATE | 03-21-94 | Acurex Environmental Corporation | | |
| | | | | CHK | | | PROJECT | | |
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| | | | | APPD | | | HPR PROCESS AND INSTRUMENTATION DIAGRAM | | |
| | | | | PROJECT NO. | 8570 - 300 | | | | |
| | | | | SCALE | NONE | | | | |
| | | | | ORIGINATING OFFICE | CAGE NO. | | SIZE | DWG. NO. | SHEET |
| | | | | Mountain View, CA | 08305 | | B | 8570G003 | 2 of 5 |
| | | | | Durham, NC | 08301 | | | | REV |
| | | | | Jefferson, AR | 08304 | | | | D |

| LT | DESCRIPTION | APPD | DATE | NUMBER | TITLE |
|----|---|-------|----------|--------|-------|
| D | CE-CERT AS-BUILT REVISION | MSA | 12-16-98 | | |
| C | CE-CERT AS-BUILT REVISION | ZK/MV | 1-22-98 | | |
| B | REVISED SHEETS 3 & 4. NO CHANGES TO THIS SHEET. | DJT | 7-15-97 | | |
| A | RELEASED FOR CONSTRUCTION | DJT | 4-25-97 | | |

REVISIONS

REFERENCE DRAWINGS

Appendix B - Error Analysis

Notation

| | |
|-----------|--------------------------|
| %C | weight percent of carbon |
| C | constant |
| dP | differential pressure |
| η | efficiency |
| M | molecular weight |
| \dot{m} | mass (or mole) flowrate |
| P | pressure |
| T | temperature |
| U | uncertainty |

Subscripts

| | |
|----|-----------------------------------|
| B | Biomass |
| BC | Carbon entering system as biomass |
| GC | Gaseous carbon |

The uncertainty, U_f , in a function, $f(x, y, z)$, can be expressed as [2]:

$$U_f^2 = \left(U_x \frac{\delta f}{\delta x} \right)^2 + \left(U_y \frac{\delta f}{\delta y} \right)^2 + \left(U_z \frac{\delta f}{\delta z} \right)^2 \quad (\text{B-1})$$

Biomass

The biomass carbon input rate is determined by

$$\dot{m}_{BC} = (\dot{m}_B)(\%C) \quad (\text{B-2})$$

which results in an uncertainty expressed as

$$U_{BC}^2 = (U_B \%C)^2 + (\%C U_{\dot{m}_B})^2 \quad (\text{B-3})$$

The mass flow rate of biomass will be 50 lbs/hr. With an uncertainty of .5%, the mass flow rate uncertainty will be .25 lb/hr. The relative uncertainty of 3% in the carbon content corresponds to an uncertainty of 1.4% carbon by mass, for wood which contains 43.3% carbon by mass.

Substituting values into equations B-2 and B-3 gives a biomass carbon input rate of 0.821 ± 0.025 kmol C/hr.

Gaseous Carbon Flow Rate

The gaseous flow rate is determined by

$$\dot{m} = C \sqrt{\frac{M P dP}{T}} \quad (\text{B-4})$$

which results in an uncertainty expressed as

$$U_{\dot{m}}^2 = \left(\frac{U_P \dot{m}}{2P} \right)^2 + \left(\frac{U_{dP} \dot{m}}{2dP} \right)^2 + \left(\frac{U_T \dot{m}}{2T} \right)^2 + \left(\frac{U_C \dot{m}}{C} \right)^2 \quad (\text{B-5})$$

for the inlet gases. However, for the effluent, there is uncertainty in the molar mass, because it must be determined, by GC/TCD, using the relation

$$\bar{M} = \sum (yM) \quad (\text{B-6})$$

where \bar{M} denotes the average molar mass of the mixture, and y and M denote the mole fraction and the molar mass of each component, respectively. This yields an uncertainty expressed as

$$\frac{U_{\bar{M}}}{\bar{M}} = \sum (U_y M)^2. \quad (\text{B-7})$$

An estimate of the uncertainty of a GC/TCD is about $\pm 1.1\%$ of the mole fraction measurement. Using the mole fraction of H_2 for each gas in the mixture results in an uncertainty of 0.198 g/mol in the molar mass of the effluent.

For the effluent stream, therefore, the expression for the flow rate uncertainty is

$$U_{\dot{m}}^2 = \left(\frac{U_P \dot{m}}{2P} \right)^2 + \left(\frac{U_{dP} \dot{m}}{2dP} \right)^2 + \left(\frac{U_T \dot{m}}{2T} \right)^2 + \left(\frac{U_{\bar{M}} \dot{m}}{2\bar{M}} \right)^2 + \left(\frac{U_C \dot{m}}{C} \right)^2 \quad (\text{B-8})$$

Table B shows values for the parameters needed to calculate flow rate uncertainty.

Table B. Parameters necessary for flow rate error calculation.

| | |
|--|-----------------|
| Flowmeter Pressure (psia) | 441 |
| Pressure error (psia) | 1.5 |
| Diff. Pres. (inH ₂ O) | 27.7 |
| Diff. Pres. error (inH ₂ O) | 0.0554 |
| Temp. (R) | 536.4 |
| Temp. error (R) | 3.96 |
| Gas Stream | Flowrate |
| | (kmol/h) |
| CO | 0.3377 |
| CO ₂ | 0.1792 |
| CH ₄ | 0.5406 |
| effluent | 3.056 |
| Effluent composition | mole % |
| CO | 11.05 |
| CO ₂ | 5.86 |
| CH ₄ | 17.87 |
| H ₂ O | 19.69 |
| H ₂ | 40.08 |
| N ₂ | 5.31 |
| molar mass | 14.4 |
| Uncertainty in molar mass | 0.198 |

In the CO, CO₂, and CH₄ streams, the molar carbon flow rate uncertainty is equal to the flow rate uncertainty because the gases each contain one mole of carbon per mole of gas. However, the effluent stream has the composition specified in Table B-1. Thus, the effluent contains 0.346 moles of carbon per mole of effluent. Multiplying the flow rate uncertainty by 0.346 gives the carbon flow rate uncertainty for the effluent, which is also the total uncertainty in the gaseous carbon flow rate exiting the system, $U_{GC, out}$.

Substituting values into Equation B-5 gives the uncertainty values specified in Table 2.

Total Gaseous Carbon Entering

The total carbon entering the system is the sum of the carbon flow rates for the CO, CO₂, and CH₄ streams. The uncertainty in the carbon flow rate entering is then expressed as

$$^2_{GC, in} = U_{CO}^2 + U_{CO_2}^2 + U_{CH_4}^2 \quad (\text{B-9})$$

When the appropriate values, shown in Table 3, are substituted into Equations B-6 and B-7, the total gaseous carbon entering the system is calculated to be 0.3044 ± 0.001 kmol/hr.

Carbon Conversion Efficiency

The carbon conversion efficiency is calculated as specified in Equation 2-1. The uncertainty in η_c is expressed by

$$U_{\eta}^2 = \left(\frac{U_{GC.out}}{\dot{m}_{BC}} \right)^2 + \left(\frac{U_{GC.in}}{\dot{m}_{BC}} \right)^2 + \left(\frac{U_{BC} (\dot{m}_{GC.out} - \dot{m}_{GC.in})}{\dot{m}_{BC}^2} \right)^2 \quad (B-10)$$

When values are substituted into Equations 2-1 and B-7, the carbon conversion efficiency calculated is 91.7 ± 5.6 % carbon conversion efficiency.

Energy Balance

The energy balance is calculated as specified in Equation 3-1. The uncertainty in this balance can be expressed as

$$U_{EB}^2 = \sum_{out} (U_m h)^2 + \sum_{in} (U_m h)^2 \quad (B-11)$$

where U_{EB} is the uncertainty in the energy balance. The uncertainties in the mass flow rates are calculated using Equation B-5. These values are shown in Table 3. The specific enthalpy values calculated by the correlations shown in Appendix C are also used. When values are substituted into Equation B-10, the result is a total uncertainty of ± 836 kJ/h in the energy balance.

Appendix C - Enthalpy Balance Calculations

The specific enthalpies of formation for gaseous species were calculated using verified correlations provided by Robert Borgwardt. The correlations are shown in Table C-1. The biomass and ash enthalpy values were taken from the same process simulation flowsheet, provided by Robert Borgwardt [5].

Table C-1. Enthalpy data required for the energy balance error analysis.

| | Mass flow rate (kmol/h) | Flow rate error (kmol/h) | Enthalpy flow rate (kJ/hr) | Enthalpy error (kJ/hr) |
|---------------------|----------------------------|-----------------------------|-------------------------------|---------------------------|
| Input | | | | |
| Gases | | | | |
| CO | 0.161 | 0.00068 | -13103 | -55 |
| CO ₂ | 0.098 | 0.00041 | -34173 | -144 |
| CH ₄ | 0.045 | 0.00019 | -886 | -4 |
| N ₂ | 0.171 | 0.00072 | 4939 | 21 |
| H ₂ O | 0.286 | 0.00120 | -58924 | -248 |
| H ₂ | 1.771 | 0.00745 | 48313 | 203 |
| Total | 2.532 | 0.0076 | -53834 | 356 |
| | | | | |
| | | | | |
| Biomass | 22.700 | 0.1135 | -150394* | -752 |
| | (kg/h) | (kg/h) | | |
| | | | | |
| Effluent | | | | |
| Gas mixture | 3.056 | 0.00125 | -206491 | -84 |
| | | | | |
| Char/ash | 1.56 | N/A | 2157* | N/A |
| | (kg/h) | | | |
| | | | | |
| Enthalpy difference | | | -106* | 836 |

*Using the values reported in [5]

Since Aspen does not produce errors in enthalpy for given mass flow rate errors, Stanjan was used to calculate the specific enthalpies of the gaseous streams and enthalpy errors were calculated using equation B-11. Since the mass flow rate and therefore the energy flow rate of the reactor bottom ash and char are small compared to the other flows involved, the error in enthalpy for that stream is not considered.

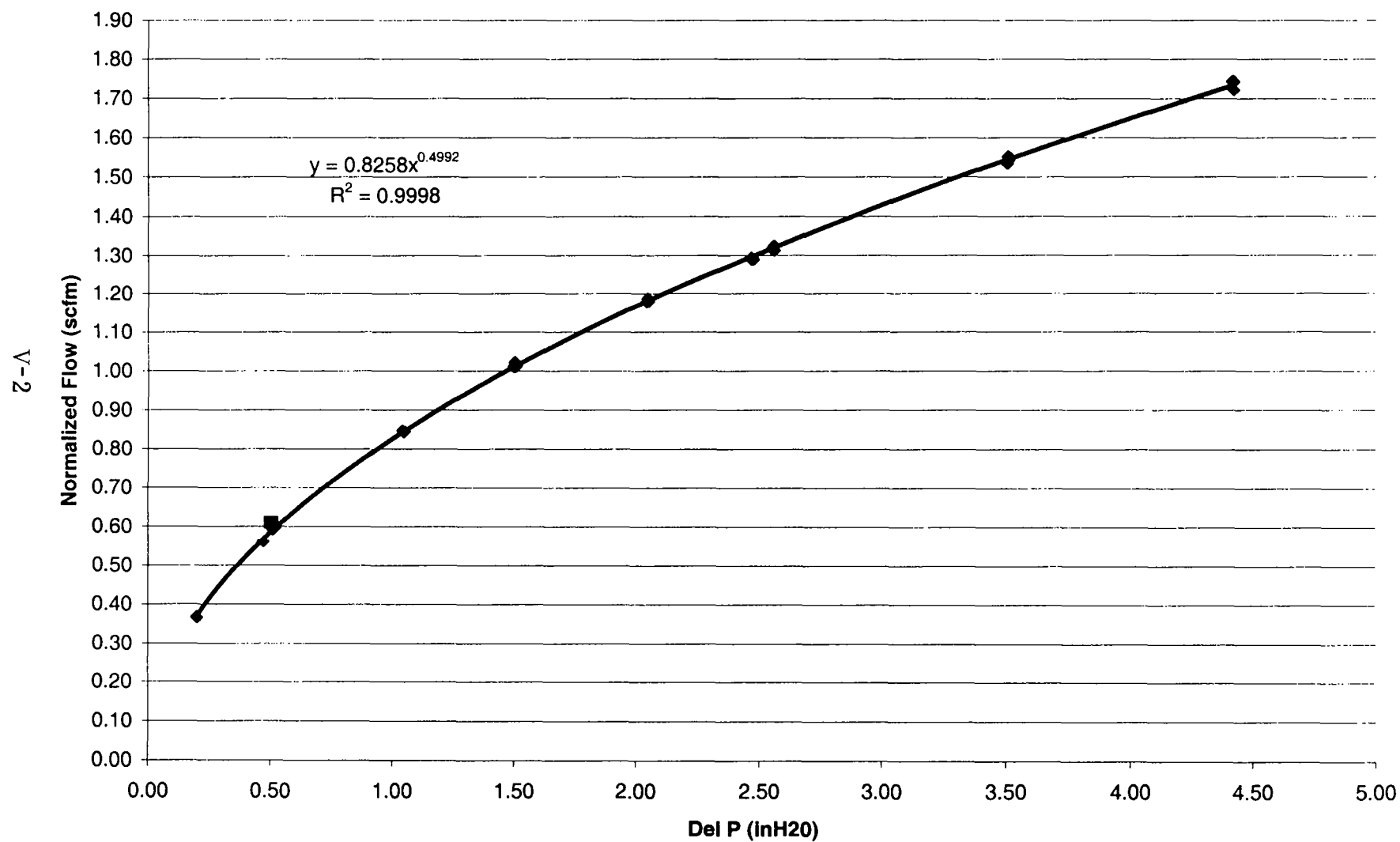
Appendix V

Calibration Curves and Tables

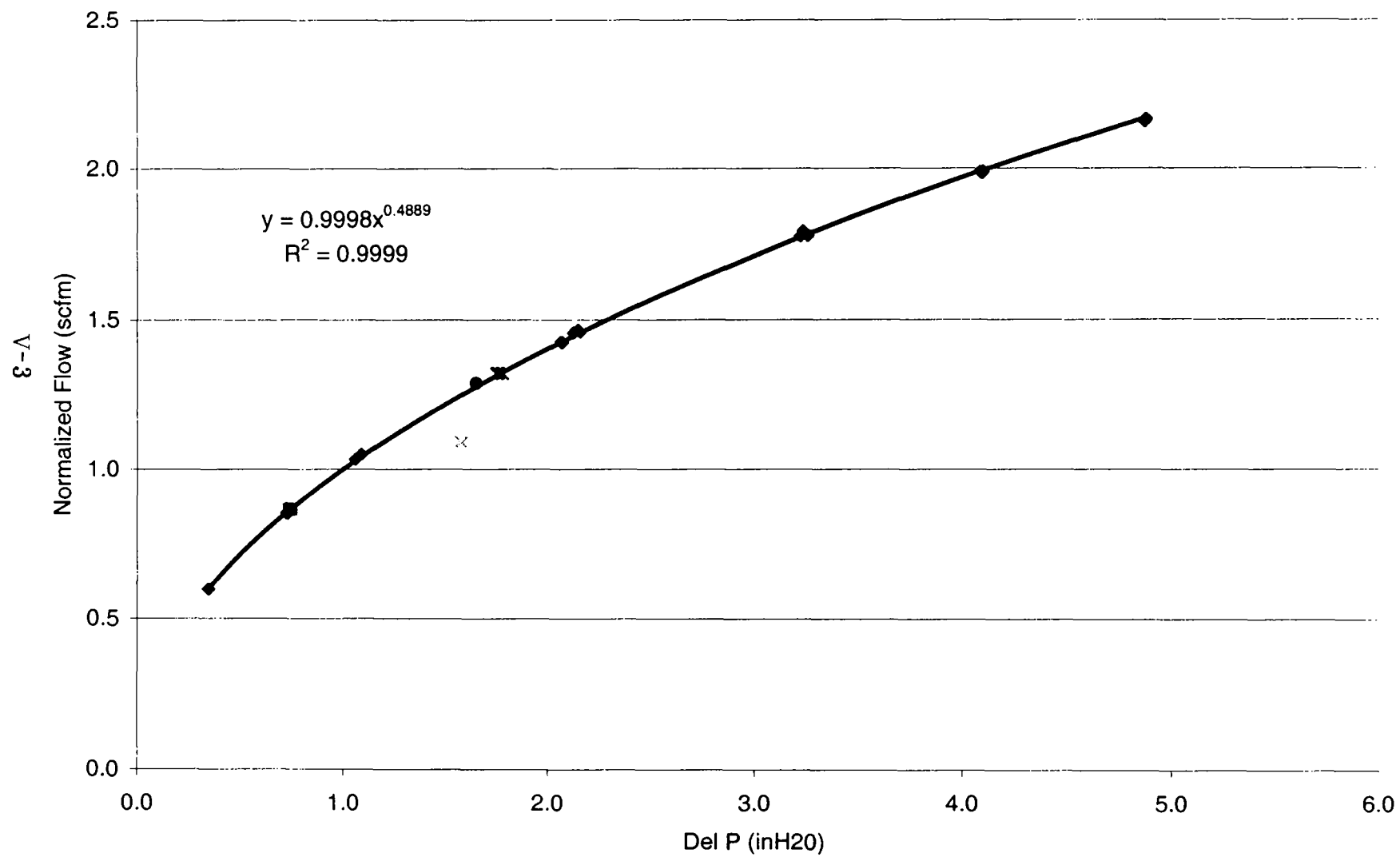
| | Designed Flow | Flow ENGL | Uncertainty Measured | Expected DelP |
|-----------------|---------------|-------------|----------------------|---------------|
| Entering | (kmol/hr) | (scfm) | % | in H2O |
| biomass | 22.7 (kg/h) | 50 (lb/hr) | in progress | n/a |
| CO | 0.161 | 2.12 | 0.3% | 0.964 |
| CO2 | 0.098 | 1.29 | 0.6% | 1.70 |
| CH4 | 0.045 | 0.592 | 1.4% | 0.513 |
| H2 | 1.771 | 23.4 | 1.9% | 3.52 |
| N2 | 0.171 | 2.25 | 0.3% | 4.73 |
| H2O | 0.286 | 6.77 | in progress | n/a |
| Exiting | (kmol/hr) | (scfm) | % | in H2O |
| effluent | 3.06 | 40.3 | 0.8% | n/a |
| ash | 1.564 (kg/h) | 3.4 (lb/hr) | in progress | n/a |

Hynol designed flowrates and uncertainties

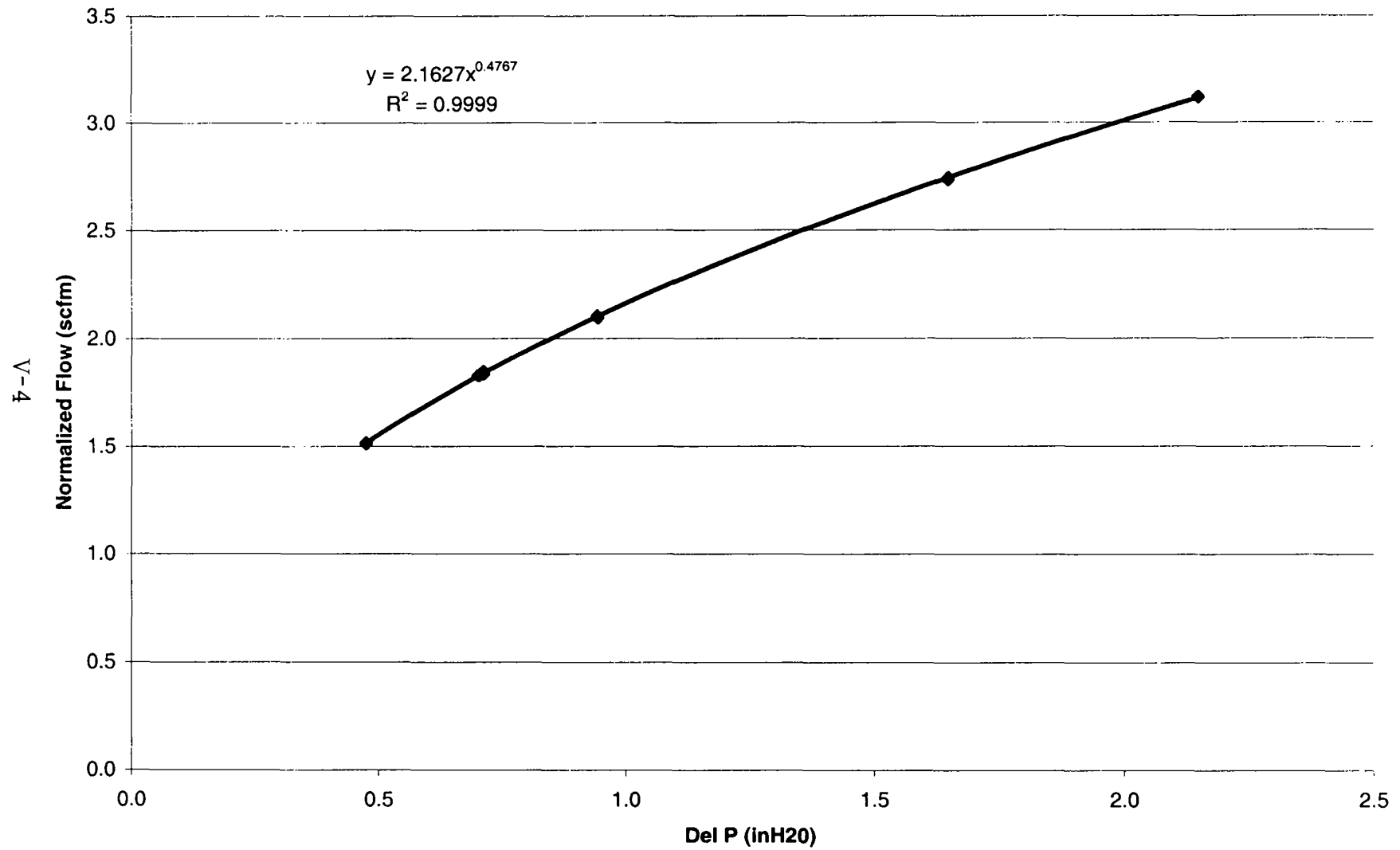
Calibration Sheet for CH4 Process Operation (PT = 450, TE = 70 F)



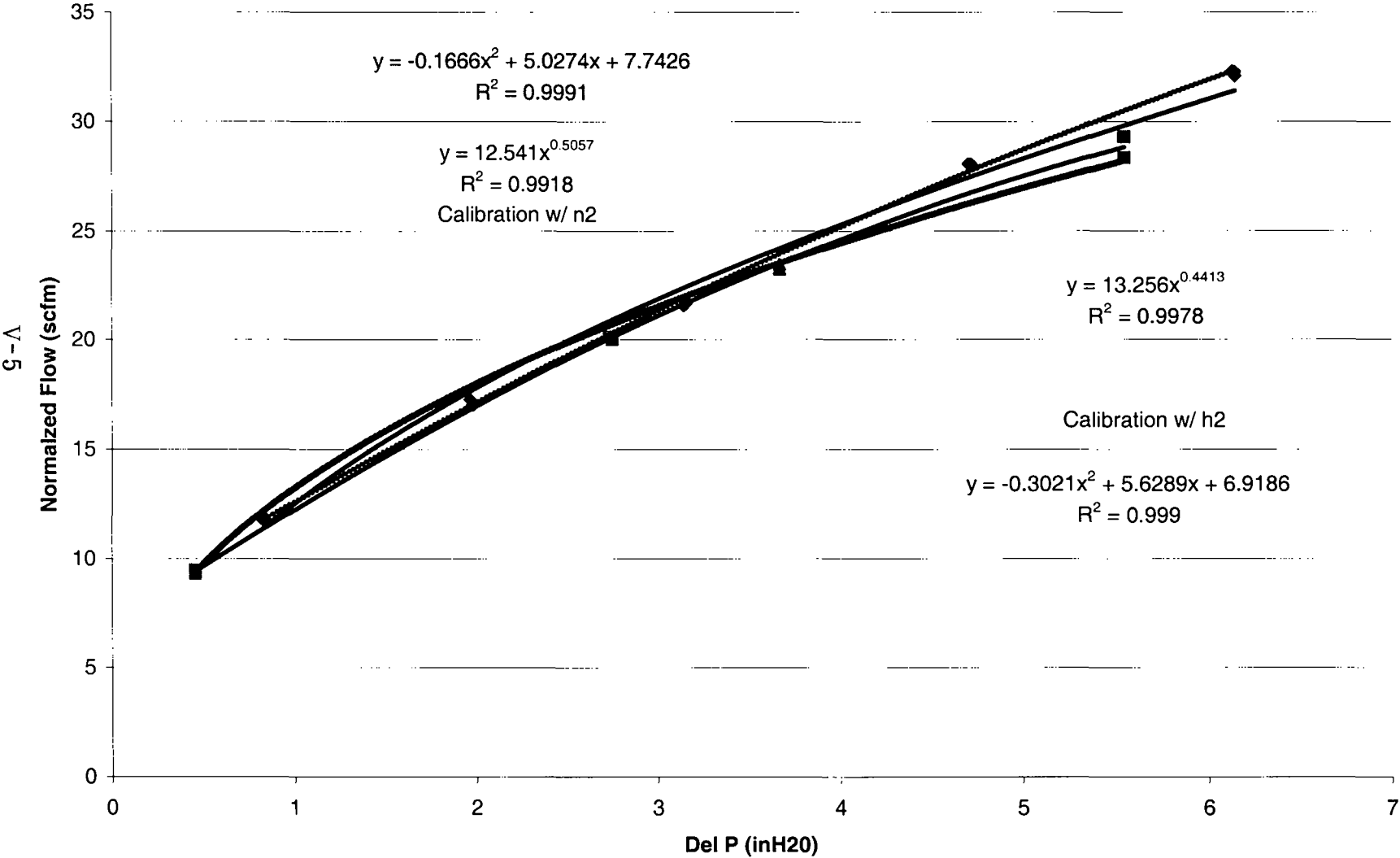
Calibration Sheet for CO2 Process Operation (PT = 450, TE = 70 F)



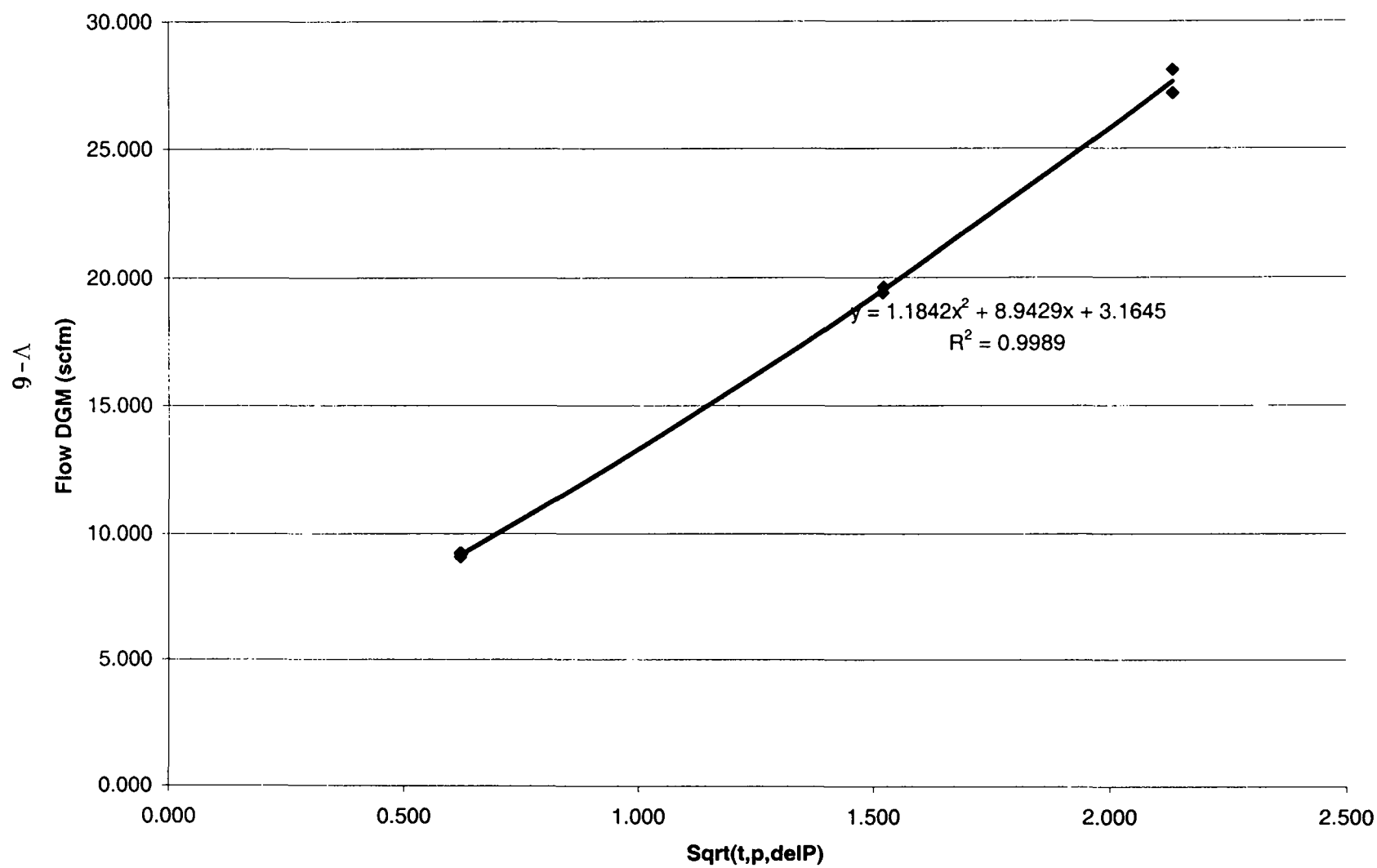
Calibration Sheet for CO Process Operation (PT = 450, TE = 70 F)



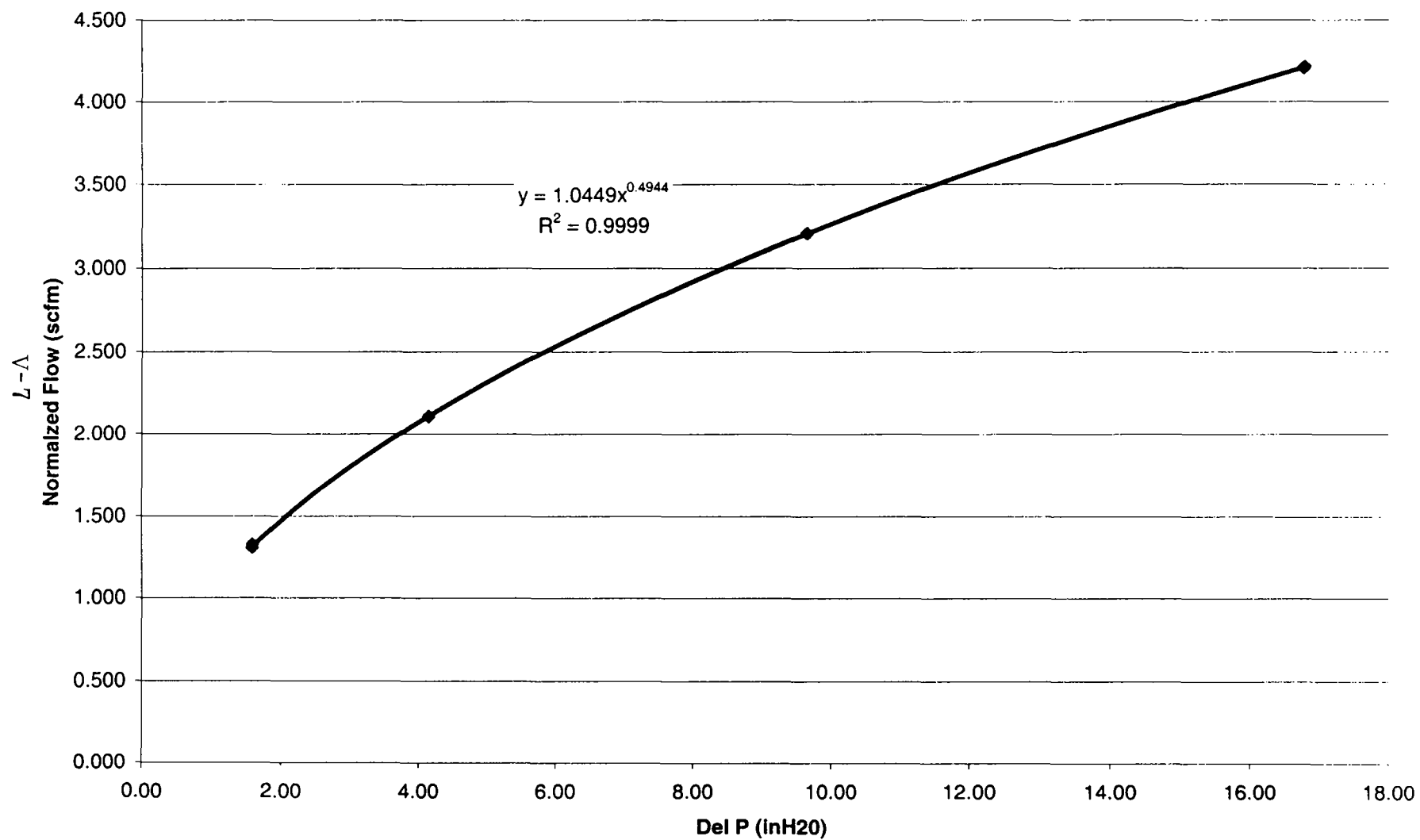
Calibration Sheet for H2 - 003 Operation (PT = 450 psig, TE = 70 F)



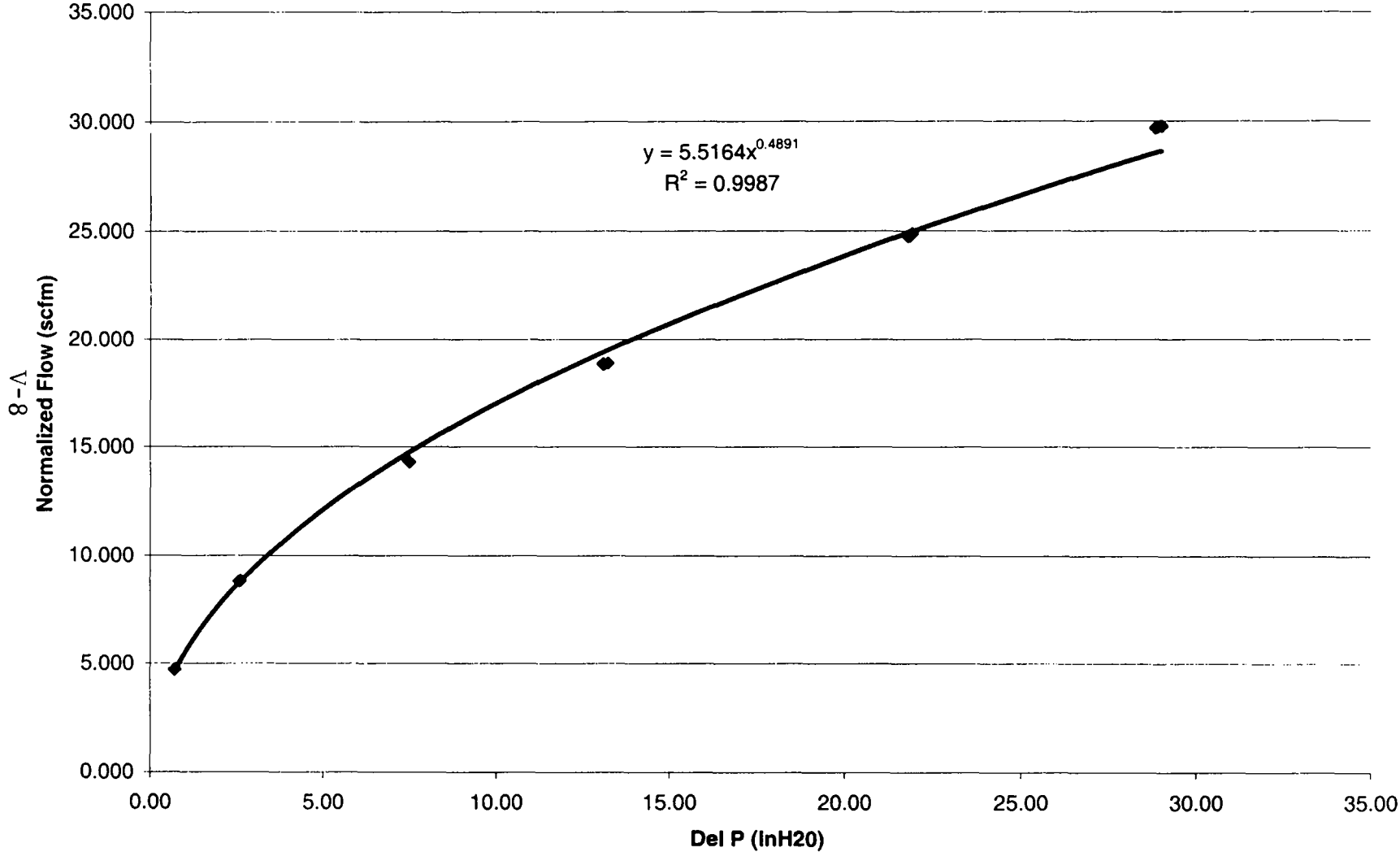
PDIT 003 flow with hydrogen gas at conditions



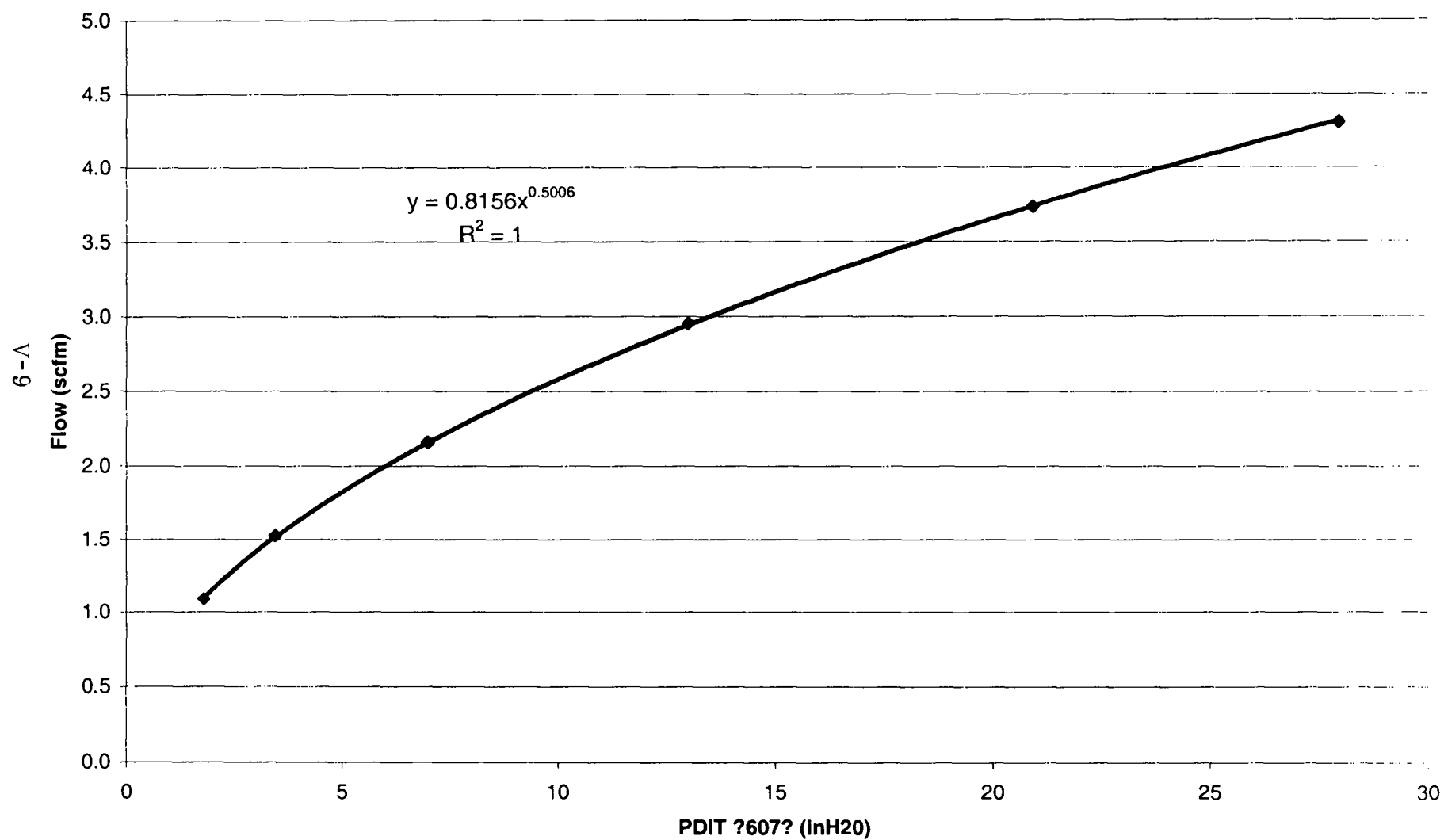
Calibration Sheet for N2 - 011 Operation (PT = 450 psig, TE = 70 F)



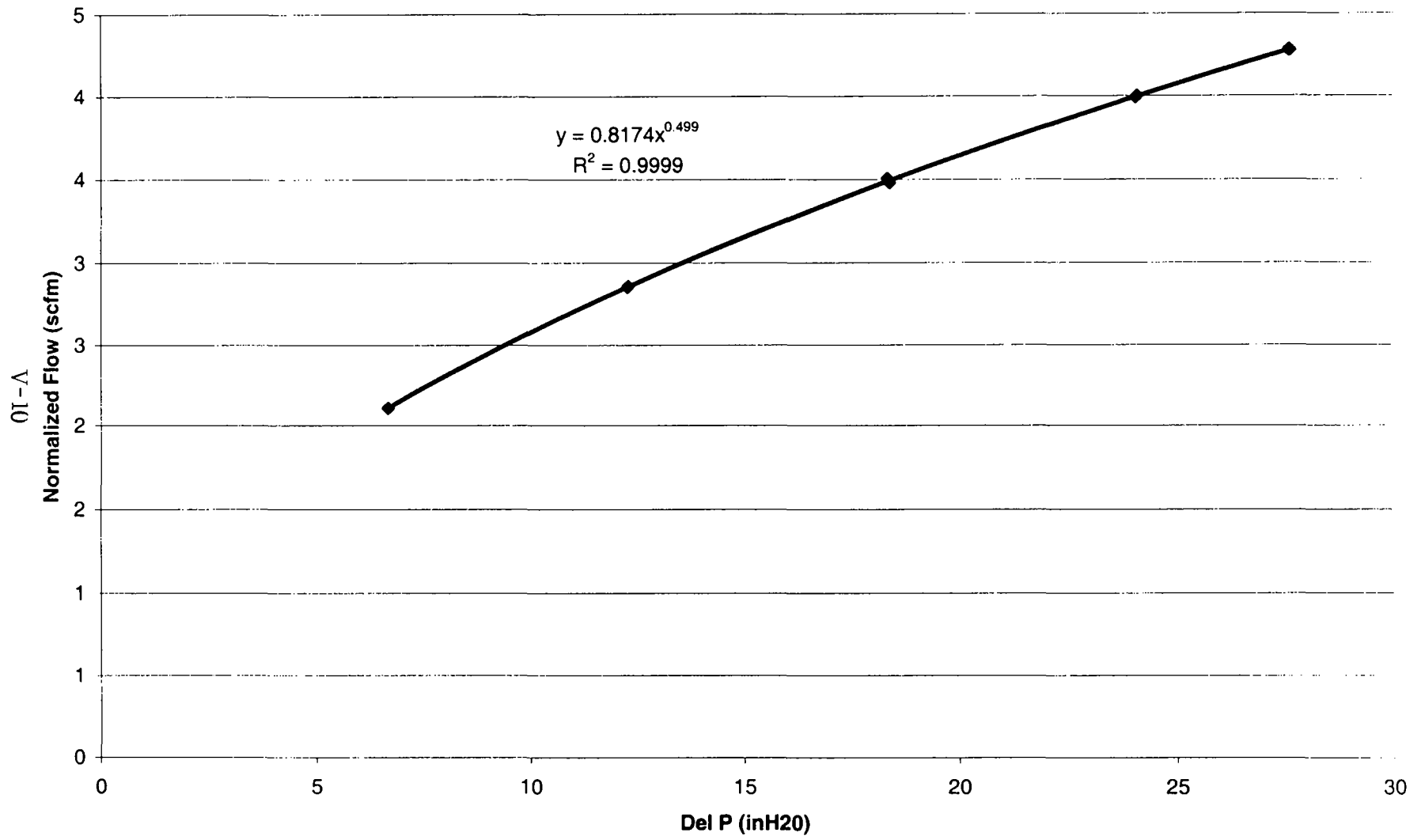
Calibration Sheet for Air Burner Operation (PT = 130 psig, TE = 70 F)



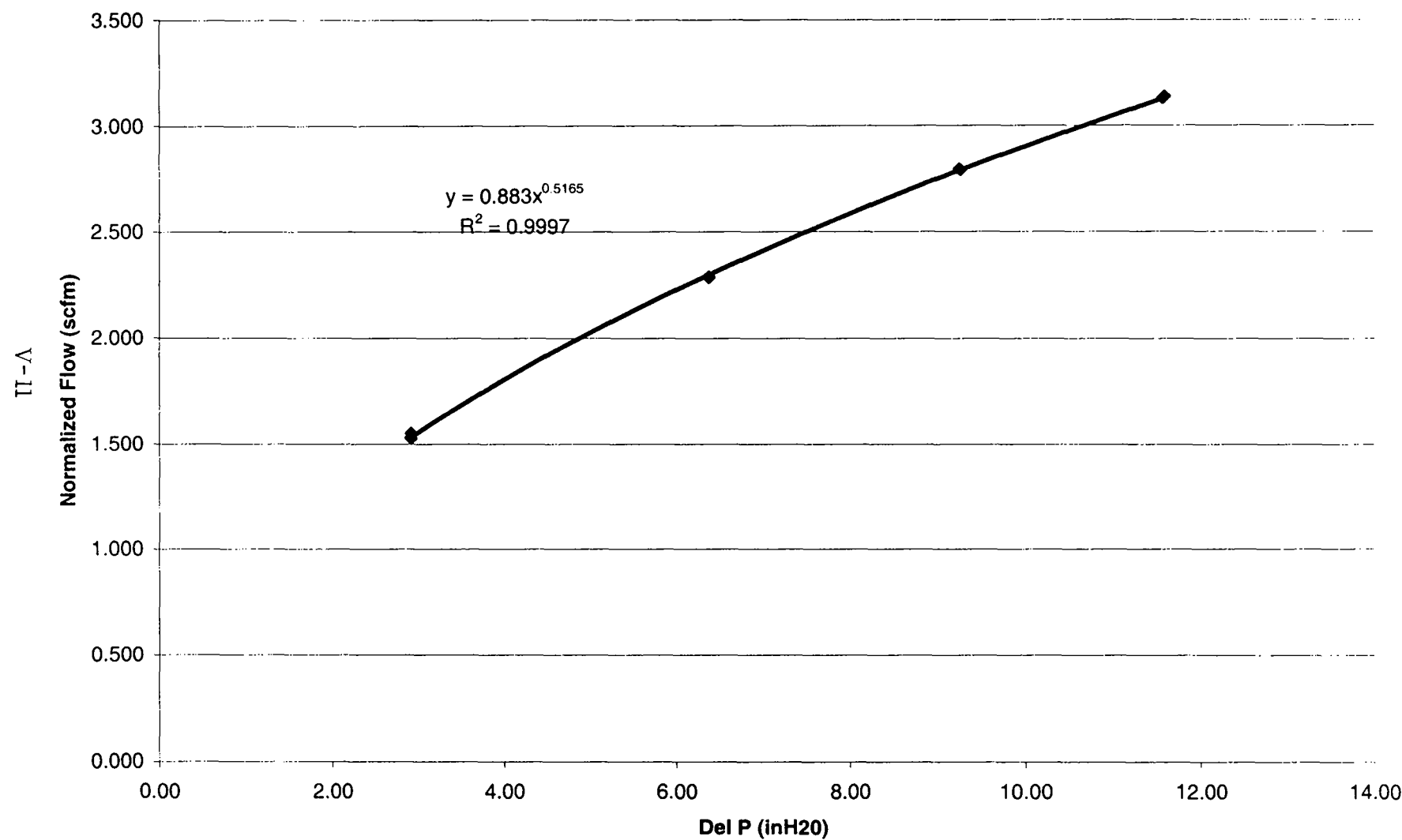
Calibration Sheet for CH4 Burner Operation (PT = 450 psig, TE = 70 F)



Calibration Sheet for CH4 Burner Operation (PT = 450 psig, TE = 70 F)



Calibration Sheet for N2 - 403 Feed System Operation (PT = 450 psig, TE = 70 F)



Appendix VI

Standard Operating Procedures

CE-CERT

STANDARD OPERATING PROCEDURE

ISSUED BY: Maintenance & Safety
John Wright

S.O.P. NO. S-001

SUBJECT: Reactor Start Up Main

PAGE: 1 OF 4

APPROVED BY: Kent Johnson

EFFECTIVE DATE: 11/1/99

REVISED DATE: 12/3/99

The purpose of this SOP provide instruction on reactor pre-start, startup, and shut down procedures. Sign and date after each instruction when completed.

PreStart Up:

1. Complete and post the test notification form. See SOP xx for details. _____.
2. Analyze biomass *moisture* _____ (Three times each location).
See SOP ## for details. Record data in log book. _____.
3. Calibrate *H2* flow system at _____ scfm (~450 psi). Result should be less than $\leq 2\%$
from DGM flow. See SOP 010001 for details. _____.
4. Calibrate *N2-011* flow system at _____ scfm (_____ psi). Result should be less than
 $\leq 2\%$ from DGM flow. See SOP 010001 for details. _____.
5. Calibrate *N2-403* flow system at _____ scfm (_____ psi). Result should be less than
 $\leq 2\%$ from DGM flow. See SOP 010001 for details. _____.
6. Calibrate *Effluent* flow system at _____ scfm. Result should be less than $\leq 2\%$
from DGM flow. See SOP 010005 for details. _____.
7. Calibrate *Air* flow system. Result should be less than $\leq 2\%$ from DGM flow.
See SOP ## for details. _____.
8. Calibrate *H2 %* system (1.5 slpm through DGM). Result should be less than
 $\leq 2\%$ from desired. See SOP ## for details. _____.
9. Calibrate *Biomass flow* system. Result should be less than $\leq 2\%$ from measured.
See ## for details. _____.
10. Prime N2 and NG compressed gas cylinders. See SOP xx for details. _____.
11. Initialize valves. See SOP xx for details. _____.

12. Confirm operation of burner. See SOP ## for details. _____.
13. Confirm operation of electric heaters. See SOP ## for details. _____.
14. Confirm operation of the Mogas valves and Everlasting valves at 0 psi. See SOP xx for details. _____.
15. Inspect PDIT 483 – 489 lines for blockage. Clean as necessary. _____.
16. Prepare sample system plumbing, filters, and instruments. See SOP xx for details (pre start sample should go through non filter reg). _____.
17. Pressure test reactor to _____ psi (at least 20 % over test pressure). Leak rate should be less than 10% psi loss over 24 hours. _____.
18. Confirm operation of the Everlasting valves at _____ psi (test pressure). See SOP xx for details. _____.
19. Move NG cylinders to Flare Stack and set NG compressor up with N2. See SOP xx for details. _____.
20. Confirm operation of flare stack. See SOP ## for details. _____.
21. If PreStart is successful, order hydrogen as needed for the test _____ six packs. _____.

Start Up (PreHeating):

22. Set Air flow to ~10 scfm at 25-30 psig through electric heater. _____.
23. Start electric heaters (Max Element Temp is 3090 °F in air). See SOP xx for details. _____.
24. Set pressure regulator, PICV-xxx on sample system, to get desired flow through DGM (1 revolution ~33 seconds). _____.
25. Add _____ blocks dry ice to impinger water bath. Try to maintain an exit temperature less than 55 °F. See SOP xx for details. _____.
26. Once TE-020 is > _____ °F start burner. See SOP xx for burner startup. _____.
27. Maintain burner temperature by adjusting NG and Air flow (do not exceed 100 °F/hr at a maximum of 2000 °F at TE-Pilot or TE-020). See SOP xx for detail. _____.
28. Continue to operate burner until TE-809b is greater than 1472 °F and the temperature distribution is less than 200 °F between TE-809b and TE-811. (exg TE-809b = 1490 then TE-811 > 1490-200 = 1290 °F). It may be necessary to add air and/or NG through the Mogas valves (FV-858) to achieve bed temperatures of 1472 °F. See SOP xxx for detail. _____.
29. Once TE-809b is greater than 1472 °F and the temperature distribution is less than 200 °F between TE-809b and TE-811, Turn off the burner and depressurize. _____.
30. Once the pressure is 0 psi, add _____ + 0.6L InvestoCast50. See SOP xx for details. _____.

31. Turn the burner back on and perform _____ successful ash removal cycles at ~25 psi while heating the bed material to 1472 °F. See SOP xx for details. Note: Approximately 600 ml of bed material will be lost. This has been considered in the total bed volume added. _____.
32. Record the total pressure drop across the distributor and reactor (~ 15 inH₂O). _____.
33. Prime _____ biomass-fill cycles into T-801. _____.

Pre Hydrogasifying Setup:

34. Calibrate NDIR analyzers both zero and span. See SOP ## for details. _____.
35. Change system to have sample gas go through filtered regulator. _____.
36. Add more dry ice as necessary to maintain 55 F impinger exit temperature. _____.

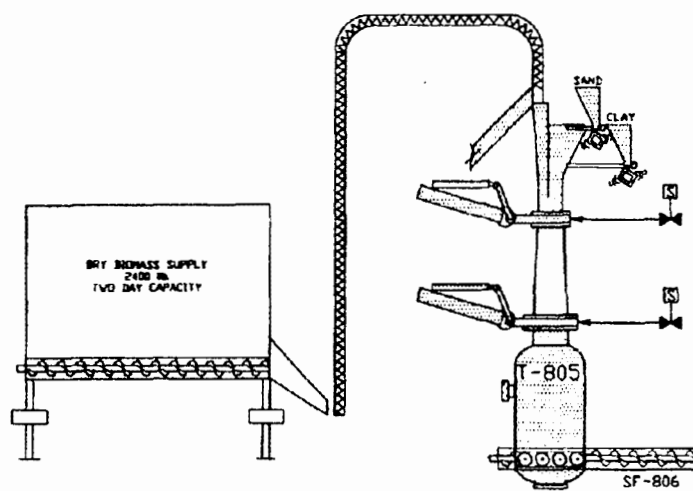
Hydrogasifying:

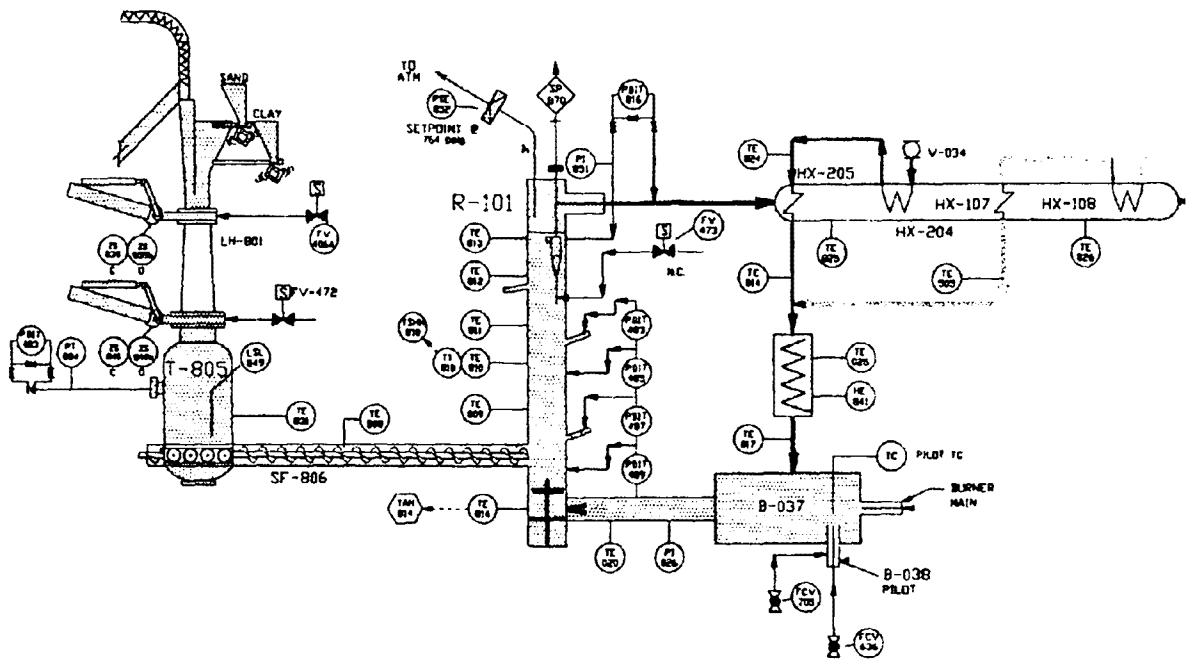
37. Start Hydrogasifying after TE-809b is greater than 1472 °F and the temperature difference is less than 200 °F between TE-809b and TE-811. _____.
38. Isolate the nitrogen & air valves (V-xx & xx) first, then shut off the burner and electric heater. See SOP xx for burner shut down details. _____.
39. Let the system depressurize by opening gate valve V-____ all the way. _____.
40. Once reactor is at 0 psi purge reactor with hydrogen by slowly add hydrogen into the reactor at a flow of 16.6 scfm. Pressure at PT-003 should be 400 psi. While purging at this flow turn on the electric heater (Max Element temp is 2100F). _____.
41. After 5 minutes of purging, close gate valve V-____ all the way to increase reactor pressure to gasifying conditions (PT-030 = 120 psi). _____.
42. Set the meter screw to _____ Hz (_____ lb/hr) and set the feed screw to 50. _____.
43. Increase electric heater control signal as necessary and let the pressure build to 105 psig before starting the feed system. (Note: bed temperatures will drop while pressurizing). _____.
44. Start the feed system once PT-030 is ~120 psi ± 10 psi. (We may want to add a little air through the heater to maintain bed temperatures ≥ 1425 °F.) _____.
45. If bed temperatures start to decrease slowly add air through the Mogas valves. Record flow in slpm on log form. _____.

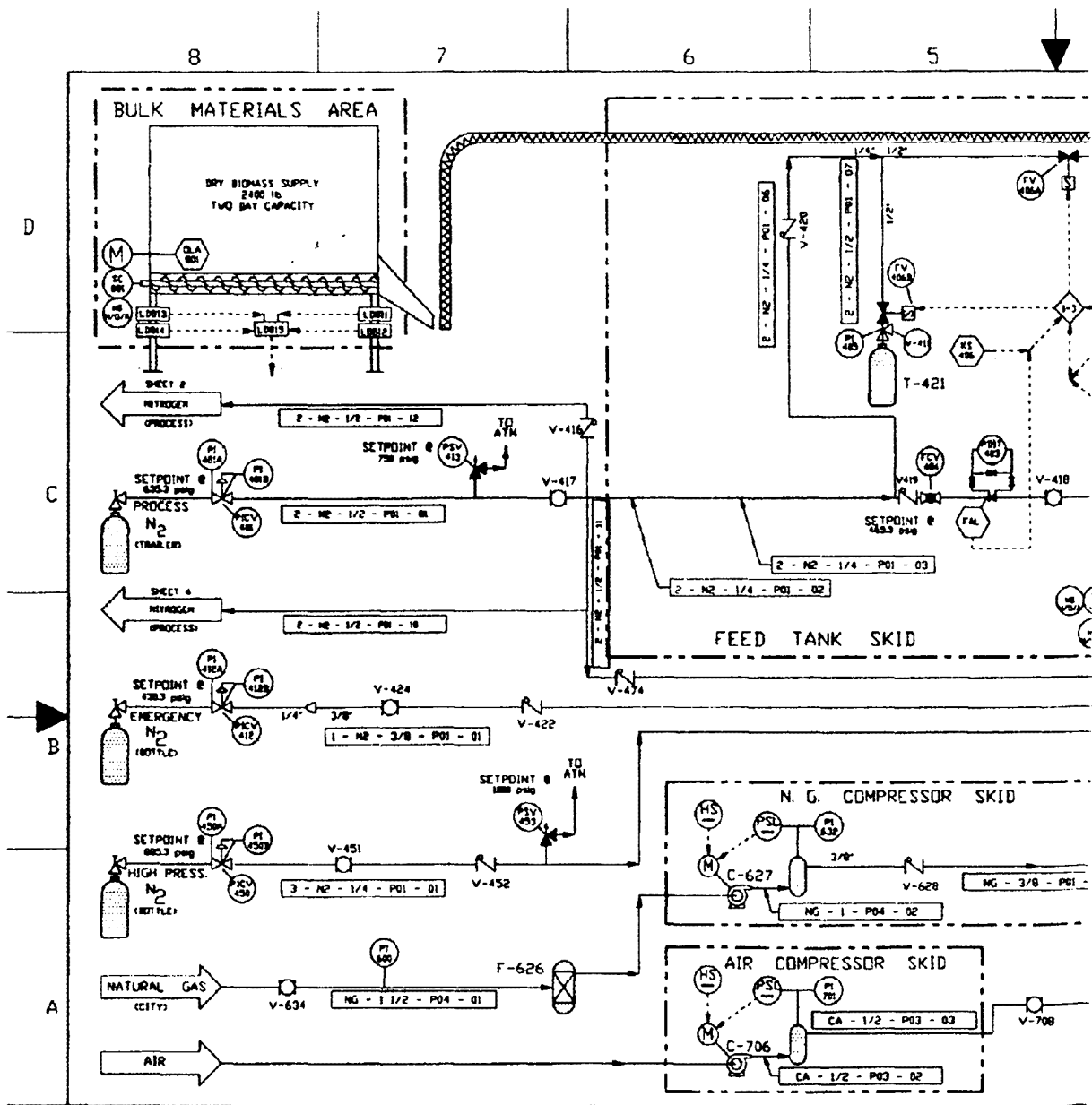
46. Continue hydrogasifying until either the hydrogen runs out or there are operating problems with the gasifier. Gasifying problems are defined as:
 - Ash removal cycles not successful
 - High temperature filter pressure drop is greater than 10 psi.
 - Bed temperatures drop below 900 °F
 - Pressure drop total (sum of PDIT 487, 485, and 483) is less than 5 inH₂O.
 - Bed height should increase ~ 12 " per hour at 25kg/hr with 80% conversion. Therefore it should be expected that the pressure drop will increase and move up the bed.
47. Once hydrogasification is completed, isolate the hydrogen valves and burn off any excess biomass in the reactor using air at a flow of 10-15 scfm through the electric heater.
48. The temperatures TE-809 will decrease when the biomass is all gone. Continue running air until TE-809 is less than 900 °F and decreasing.
49. Once TE-809 is less than 900 °F start the burner and try to bring the filter temperature down slowly. Note TE-809 should start to increase. Run the burner with excess air until the temperature at the filter exceeds 500 °F for at least 1 hour. Then slowly isolate the natural gas and air and purge the reactor with nitrogen for 5 more hours at 0 – 1 psi, ~ 2 scfm.

Appendix VII

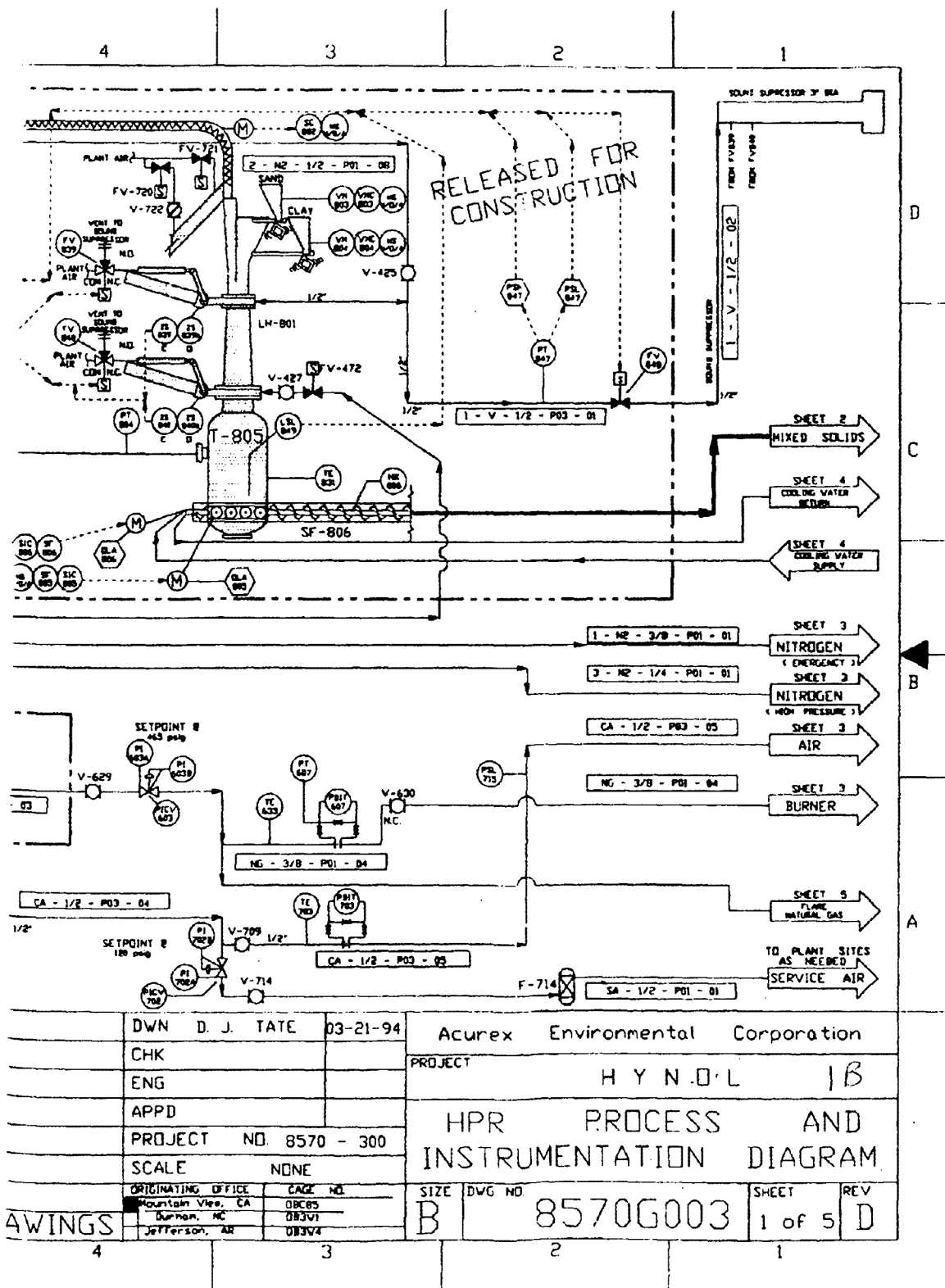
Diagrams and Locations of Sensors

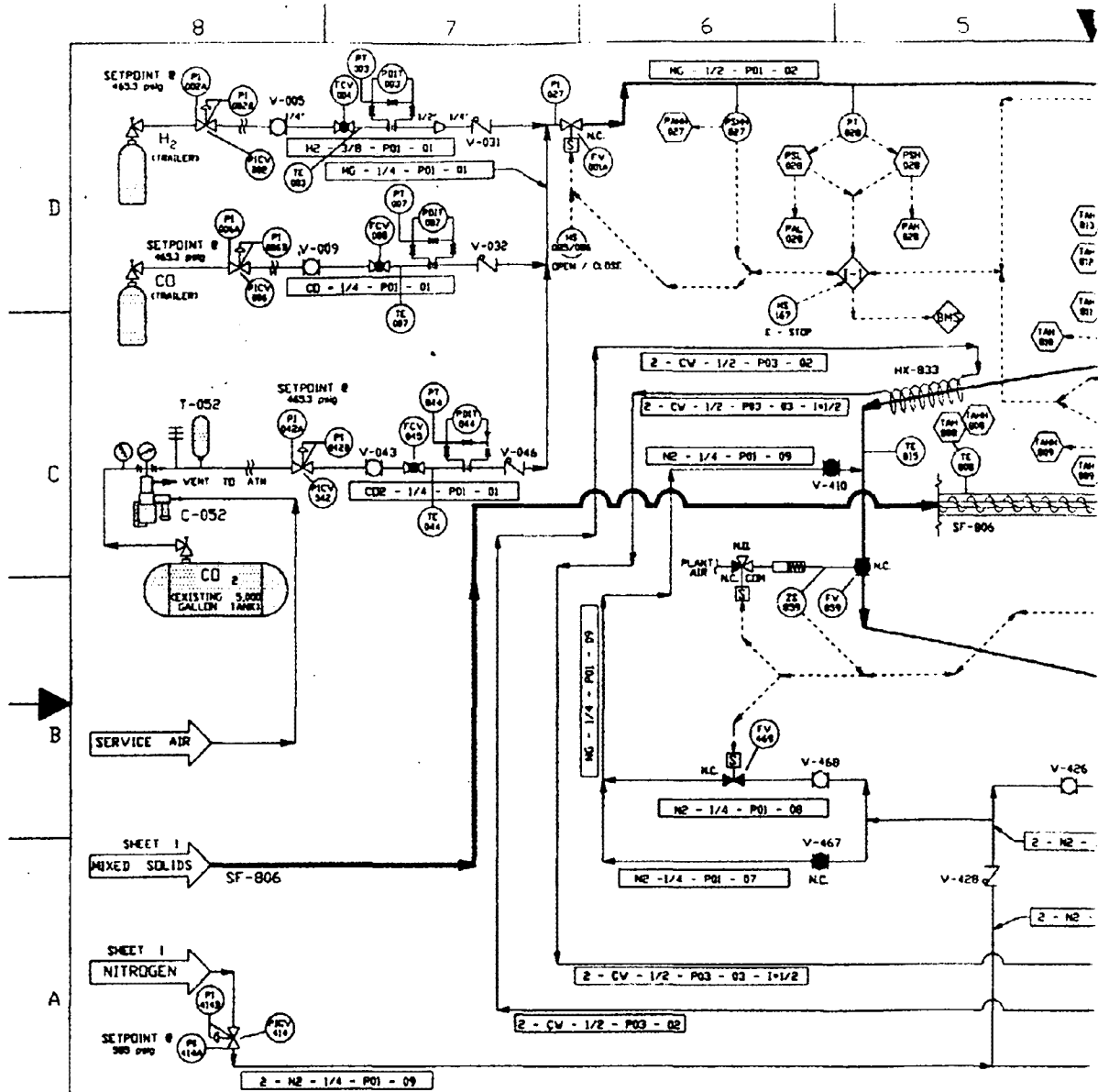




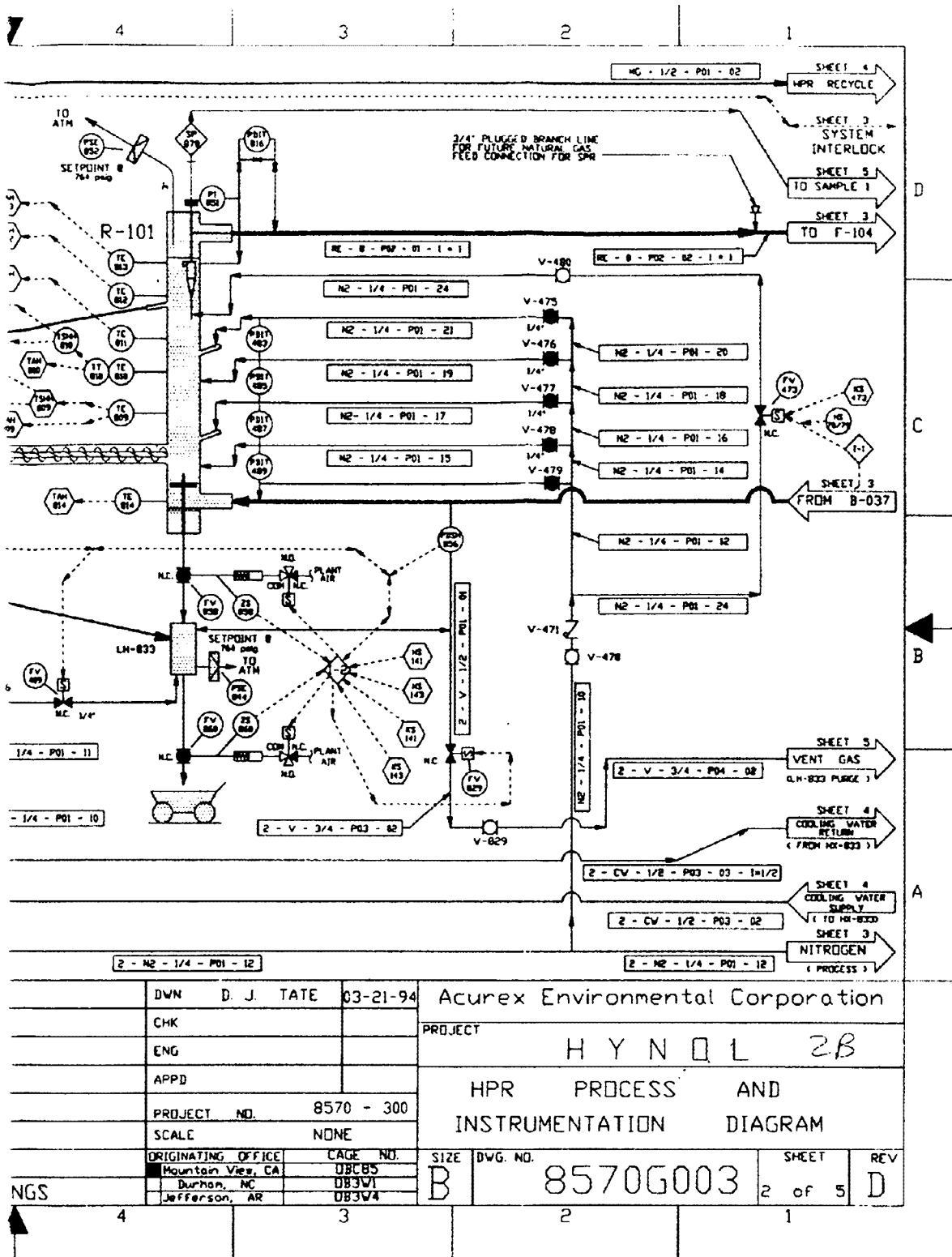


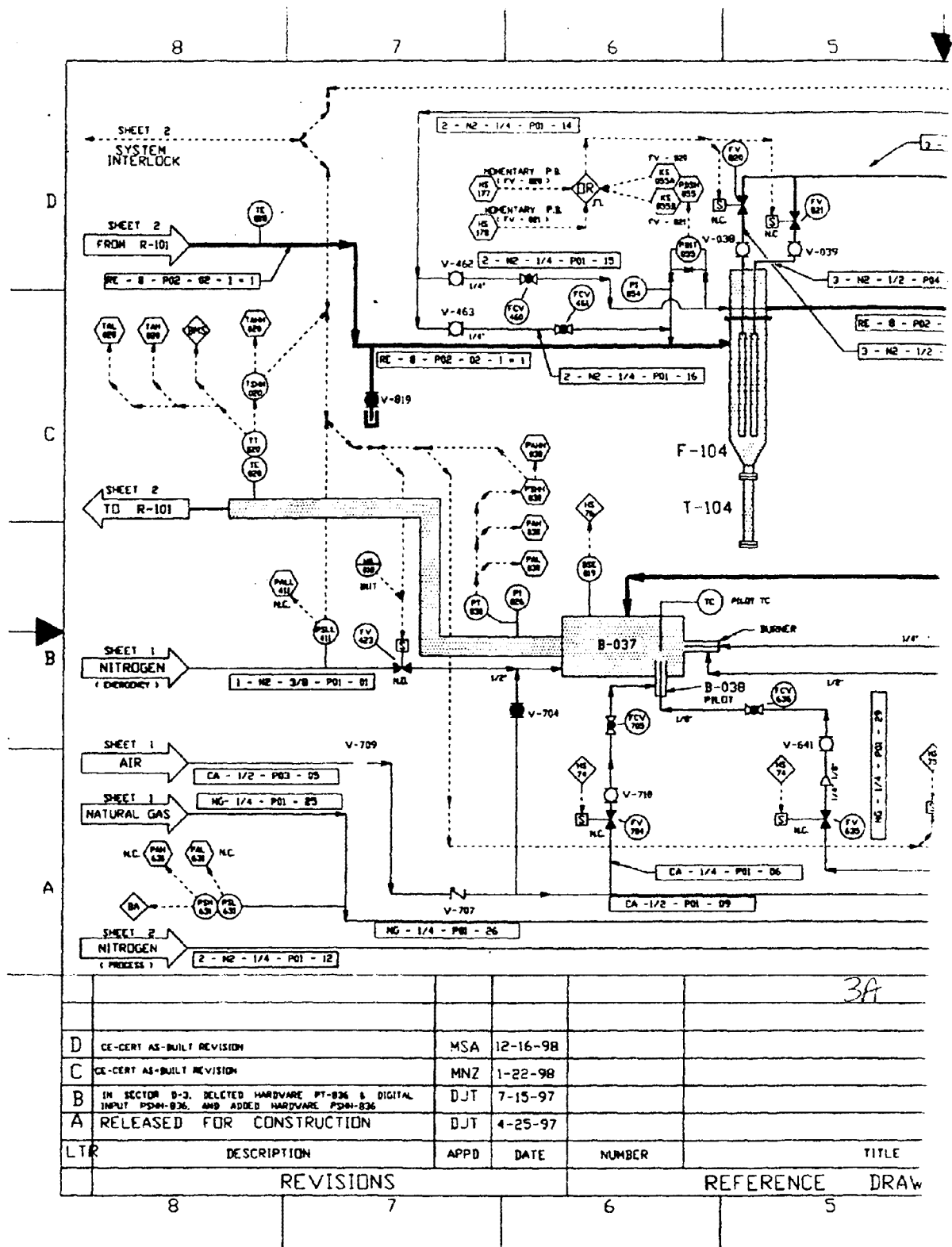
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| D | CE-CERT AS BUILT REVISION | MSA | 12-16-98 | | |
| C | CE-CERT AS BUILT REVISION | MW/ZK | 1-22-98 | | |
| B | REVISED SHEETS 3 & 4. NO CHANGES TO THIS SHEET | DJT | 7-15-97 | | |
| A | RELEASED FOR CONSTRUCTION | DJT | 4-25-97 | | |
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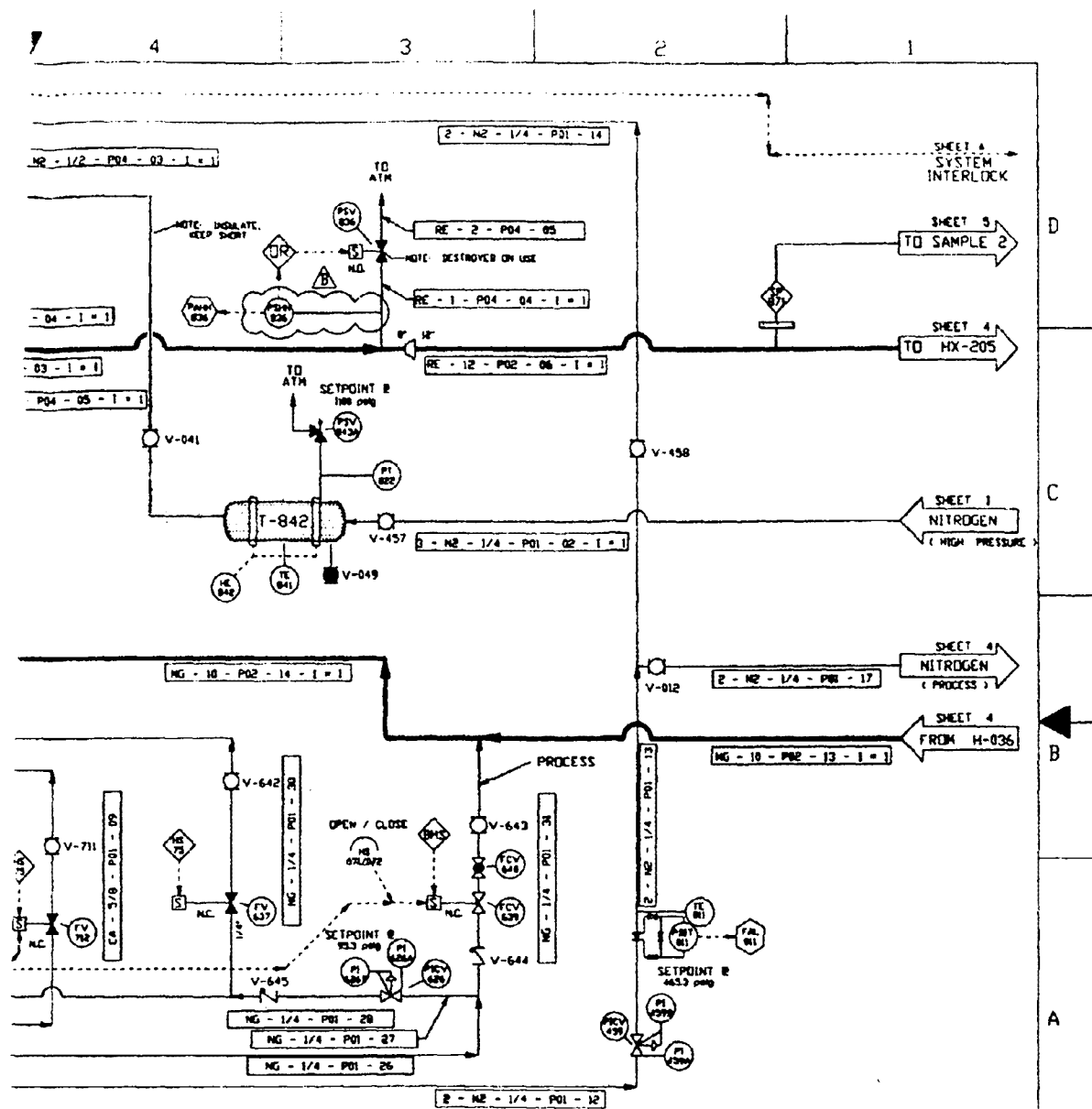




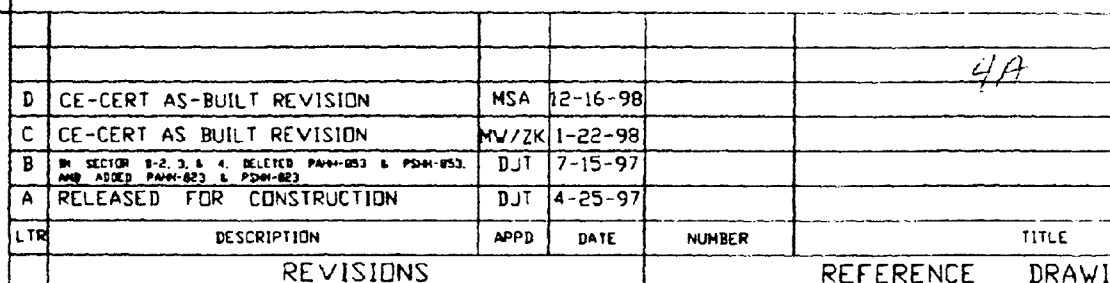
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| | | | | | | |
| | | | | | | 2A |
| D | CE-CERT AS-BUILT REVISION | MSA | 12-16-98 | | | |
| C | CE-CERT AS-BUILT REVISION | ZK/MW | 1-22-98 | | | |
| B | REVISED SHEETS 3 & 4. NO CHANGES TO THIS SHEET. | DJT | 7-15-97 | | | |
| A | RELEASED FOR CONSTRUCTION | DJT | 4-25-97 | | | |
| LTR | DESCRIPTION | APPD | DATE | NUMBER | TITLE | |
| | REVISIONS | | | REFERENCE DRAWING | | |

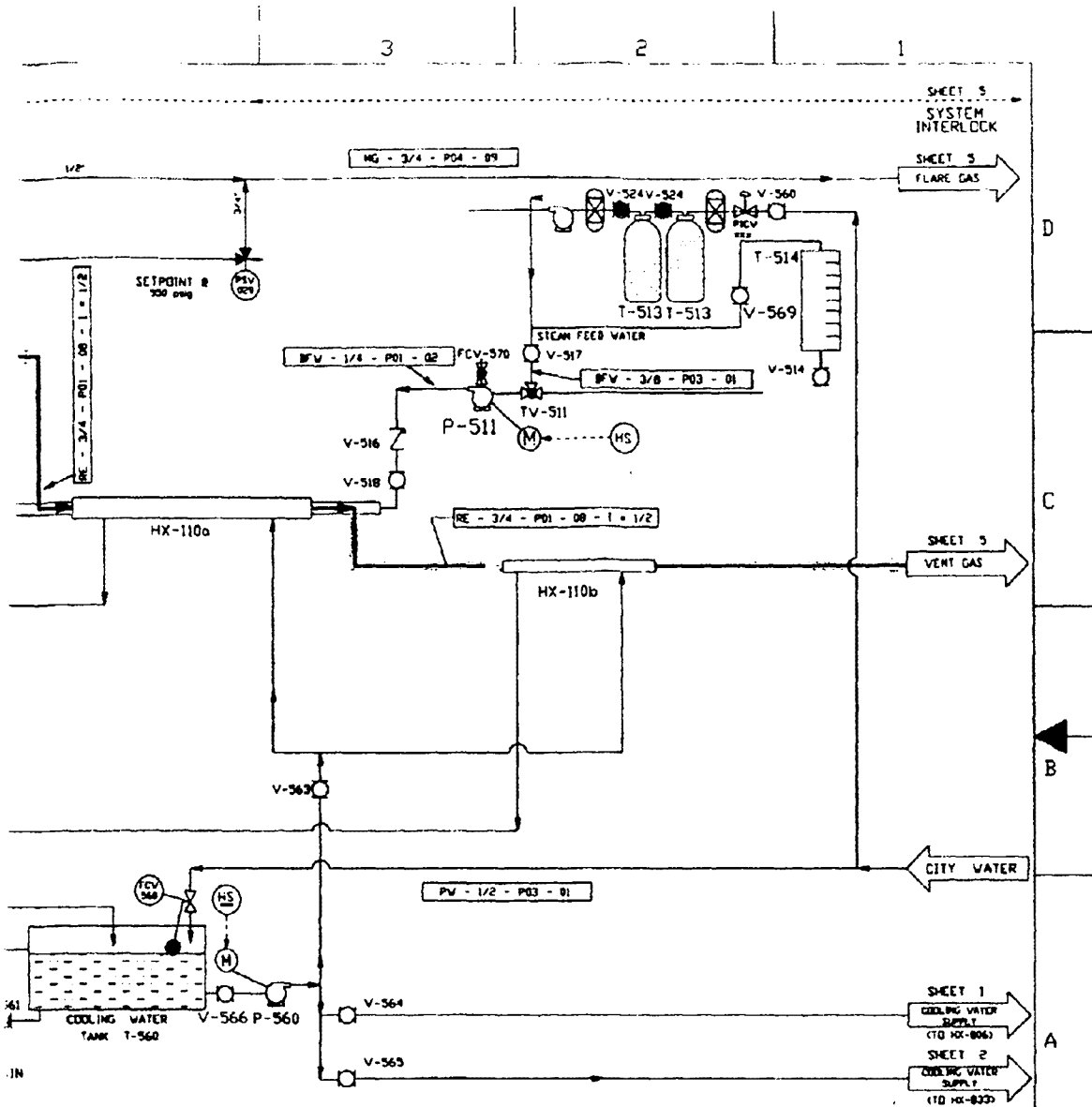




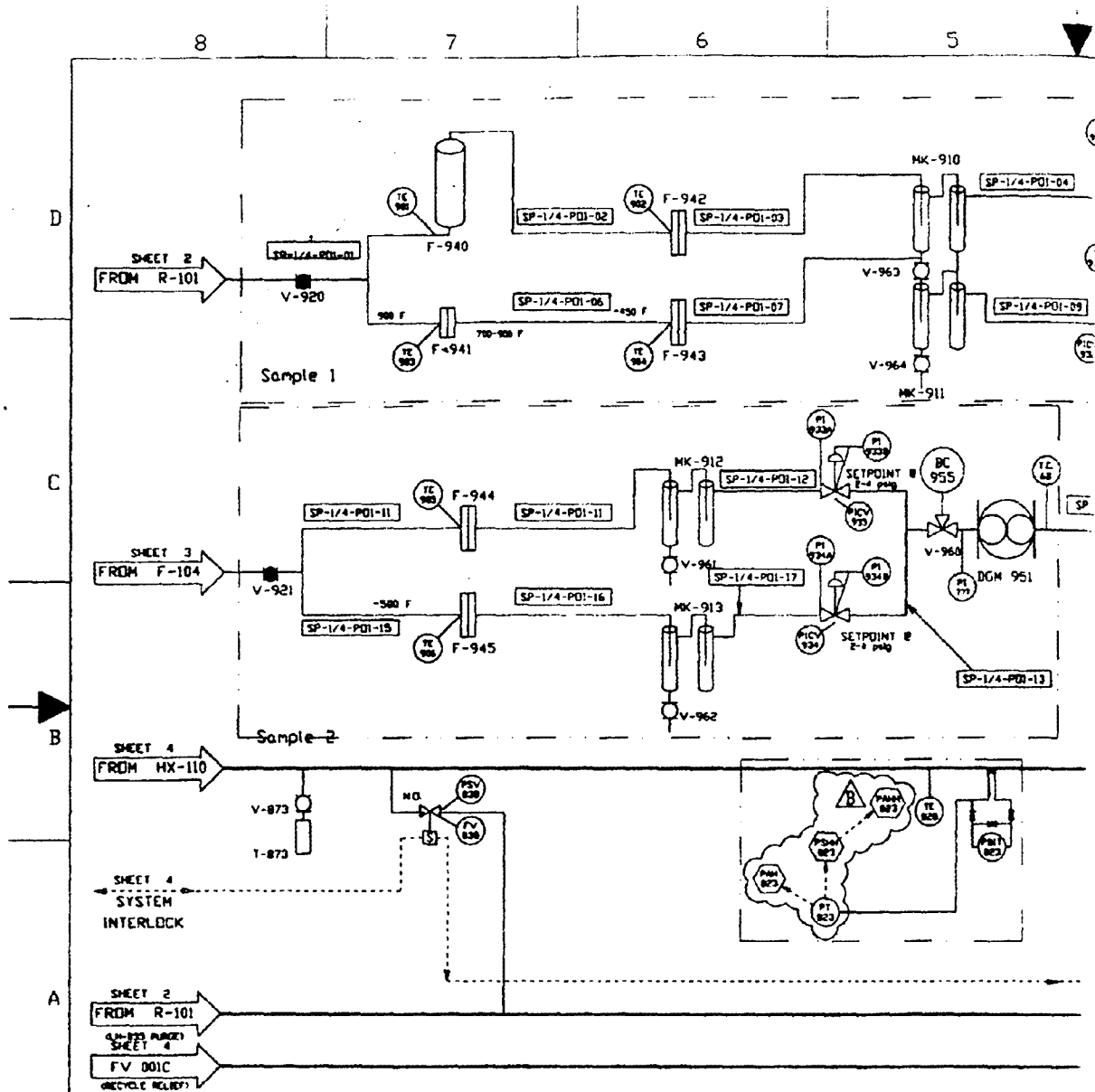


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|--------------------|----------------|----------|---|
| DWN | D. J. TATE | 03-21-94 | Acurex Environmental Corporation |
| CHK | | | PROJECT |
| ENG | | | H Y N O L 3B |
| APPD | | | HPR PROCESS AND INSTRUMENTATION DIAGRAM |
| PROJECT | NO. 8570 - 300 | | |
| SCALE | NONE | | |
| ORIGINATING OFFICE | CAGE NO. | SIZE | DWG. NO. |
| Mountain View, CA | 08305 | B | 8570G003 |
| Durham, NC | 083V1 | | |
| Jefferson, AR | 083V4 | | |
| | | | SHEET 3 OF 5 |
| | | | REV D |

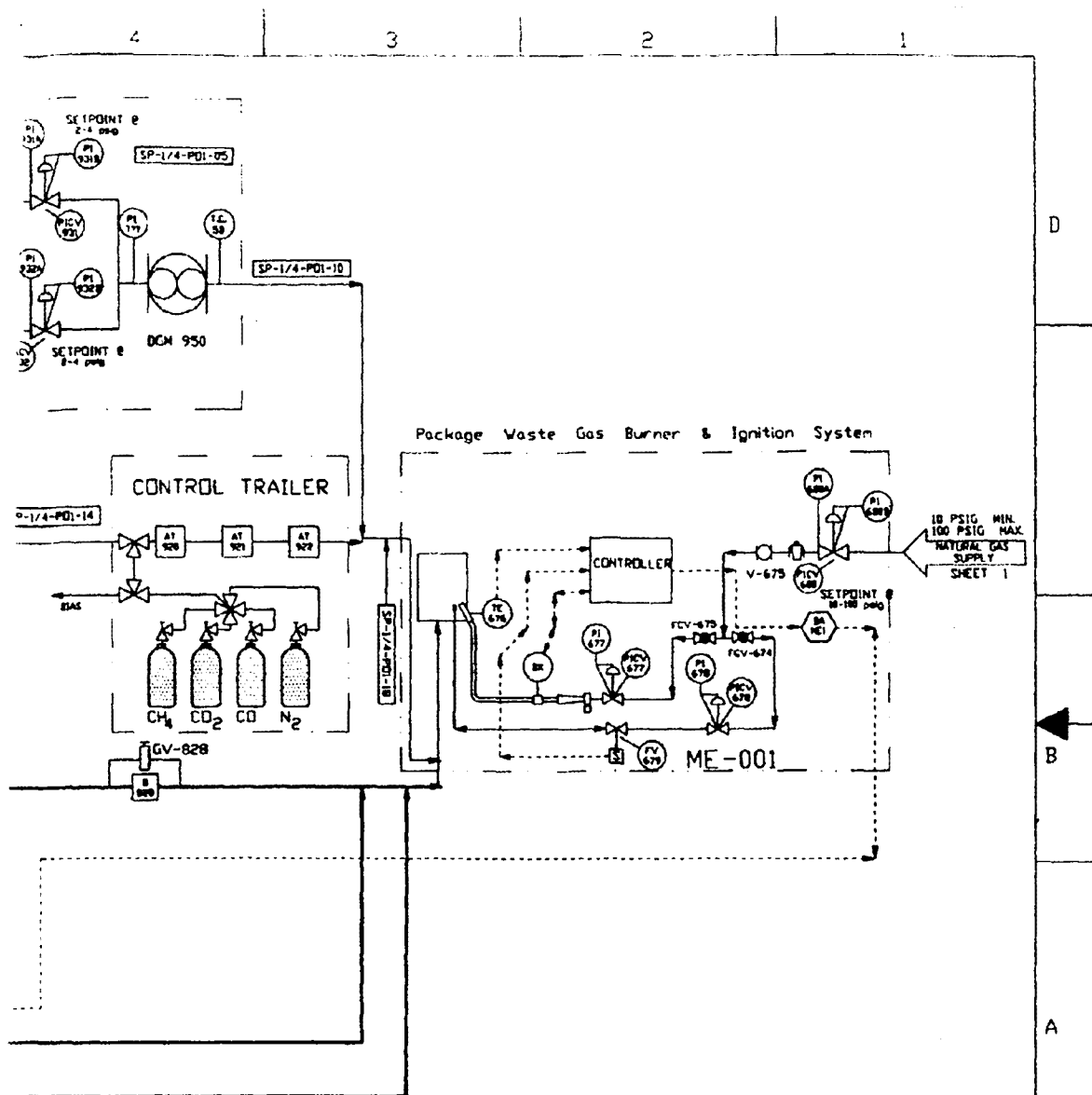




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|------------------------|------------|----------|---|----------|--------|-----|
| DWN | D. J. TATE | 03-21-94 | Acurex Environmental Corporation | | | |
| CHK | | | PROJECT | | | |
| ENG | | | H Y N Q L 4B | | | |
| APPD | | | HPR PROCESS AND INSTRUMENTATION DIAGRAM | | | |
| PROJECT NO. 8570 - 300 | | | | | | |
| SCALE NONE | | | | | | |
| ORIGINATING OFFICE | CAGE NO. | | SIZE | DWG. NO. | SHEET | REV |
| Mountain View, CA | 08C83 | | B | 8570G003 | 4 of 5 | D |
| Durham, NC | 083V1 | | | | | |
| Jefferson, AR | 083V4 | | | | | |



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|-----|--|-------|----------|-------------------|--|-------|
| | | | | | | 5A |
| D | CE-CERT AS-BUILT REVISION | MSA | 12-16-98 | | | |
| A | CE-CERT AS-BUILT REVISION | MW/ZK | 1-22-98 | | | |
| B | IN SECTOR D-3, DELETED HARDWARE PT-836 & DIGITAL INPUT PSH-836, AND ADDED HARDWARE PSH-836 | DJT | 7-15-97 | | | |
| A | RELEASED FOR CONSTRUCTION | DJT | 4-25-97 | | | |
| LTR | DESCRIPTION | APPD | DATE | NUMBER | | TITLE |
| | REVISIONS | | | REFERENCE DRAWING | | |



| | | | | | | |
|--------------------|------------|----------|---|--------|-----|--|
| DWN | D. J. TATE | 03-21-94 | Acurex / CE-CERT | | | |
| CHK | | | PROJECT | | | |
| ENG | | | H Y N O L S R | | | |
| APPD | | | HPR PROCESS AND INSTRUMENTATION DIAGRAM | | | |
| PROJECT NO. | 8570 - 300 | | | | | |
| SCALE | NONE | | | | | |
| ORIGINATING OFFICE | CASE NO. | SIZE | DWG. NO. | SHEET | REV | |
| Mountain View, CA | 083W5 | B | 8570G003 | 5 of 5 | D | |
| Durham, NC | 083W1 | | | | | |
| Jefferson, AR | 083W4 | | | | | |

| TECHNICAL REPORT DATA <i>(Please read Instructions on the reverse before completing)</i> | | |
|--|--|---|
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| 4. TITLE AND SUBTITLE Evaluation of a Process to Convert Biomass to Methanol Fuel | | 5. REPORT DATE October 2000 |
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| 15. SUPPLEMENTARY NOTES APPCD project officer is Robert H. Borgwardt, Mail Drop 63, 919/541-2336. | | |
| 16. ABSTRACT The report gives results of a review of the design of a reactor capable of gasifying approximately 50 lb/hr of biomass for a pilot-scale facility to develop, demonstrate, and evaluate the Hynol Process, a high-temperature, high-pressure method for converting biomass into methanol fuel. The report also discusses design modifications and gives preliminary results of operating the facility. Significant flaws in the initial design were discovered and corrected. | | |
| 17. KEY WORDS AND DOCUMENT ANALYSIS | | |
| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
| Pollution Biomass Gasification Carbinols Fuels Evaluation | Pollution Control Stationary Sources Methanol Hynol Process | 13B 08A, 06C 13H, 07A 07C 21D 14G |
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