

**The Hynol Process:  
A Promising Pathway  
for Renewable Production of Methanol**

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**October, 2000**



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### Additional Reading:

Dong, Y., and Steinberg, M. (1997) Hynol: An Economical Process for Methanol Production from Biomass and Natural Gas with Reduced CO<sub>2</sub> Emission. *Int. J. Hydrogen Energy* 22:10/11, pp. 917-977.

Borgwardt, R.H. (1997) Cost analysis excerpt from *Hynol Process Evaluation*. EPA-600/R-97-153.

Dong, Y. (1998) Biomass Reactivity in Gasification by the Hynol Process. *Energy & Fuels* 12:3, pp. 479-484.

Borgwardt, R.H. (1999) Transportation Fuel from Cellulosic Biomass: A Comparative Assessment of Ethanol and Methanol Options. *Proc. Instn. Mech. Engrs.* 213A pp. 399-407.



## 1. Executive Summary

A number of processes exist to convert biomass to alcohol fuels, but they tend to be too expensive to compete on the market with fossil-based fuels (e.g., gasoline or methanol produced from natural gas.) A potential solution to this persistent problem is the Hynol Process, which has demonstrated carbon conversion efficiency of >85% in bench-scale demonstrations (Borgwardt, 1997a; EPA, 1997; Dong and Cole, 1996). At this efficiency level, it is feasible that methanol can be produced for transportation use at a price comparable to that of petroleum-based fuels. Methanol can be used as a gasoline additive, a gasoline alternative, or as a feedstock for a hydrogen fuel cell. (It is also feasible to use the Hynol Process to produce a synthesis gas that can be converted to synthetic diesel fuel using a Fischer-Tropsch process, but this possibility has not been explored.)

The Hynol Process combines biomass and hydrogen at high pressure and high temperature to produce a synthesis gas and, ultimately, methanol. Once the entire process is operating, waste gas and heat left over from methanol synthesis are recycled into the Hynol reactor, providing sufficient heat and hydrogen to gasify more biomass. The closed-loop process is exothermic; this makes a strong contribution to its overall efficiency because it is not necessary to burn fuel to provide heat to the reactor.

In cooperation with the U.S. Environmental Protection Agency, the College of Engineering-Center for Environmental Research and Technology (CE-CERT) at the University of California, Riverside, has constructed the world's first and only pilot-scale facility for development and testing of the process (Figure 1-1). Additional funding has been provided by the South Coast Air Quality Management District, the Riverside County Waste Resources Management District, and CE-CERT discretionary research funding. In the phase of research now being concluded, CE-CERT identified and corrected many flaws in the EPA's reactor design. CE-CERT developed operating procedures and testing plans, and successfully operated the facility. During the spring of 2000, we concluded this phase with research on process flows, temperature optimization, and calculations of carbon conversion efficiency.

In the next phase of research, CE-CERT will make further modifications to the pilot-scale facility to enable steady-state operation. These experiments will make it possible to assess the overall efficiency of the process at the pilot scale, and to evaluate a variety of feedstocks as the source of hydrocarbons for gasification. The chemical properties of feedstocks, the chemical composition of products, and the overall process efficiency with various hydrocarbon sources will be examined. Process variables and controls also will be studied to optimize performance with one or a variety of feedstocks. Additionally, the U.S. EPA has provided CE-CERT with its original bench-scale unit. When appropriate laboratory space can be set aside, this facility can be installed and operated for smaller-scale testing of Hynol Process variables.

This research program is intended to serve three fundamental purposes at the University of California:

1. To improve our understanding of the chemical processes and engineering principles involved in renewable fuels production, and to disseminate that information for the advancement of knowledge and improvements to quality of life.

2. To contribute to our educational mission by providing research opportunities for graduate and undergraduate students.
3. To generate potential new economic activity, especially in California, contributing to job creation, new technologies, and efficiency improvements. This objective can best be achieved through collaboration and cooperation with industry.



**Figure 1-1. CE-CERT pilot-scale Hynol facility.**

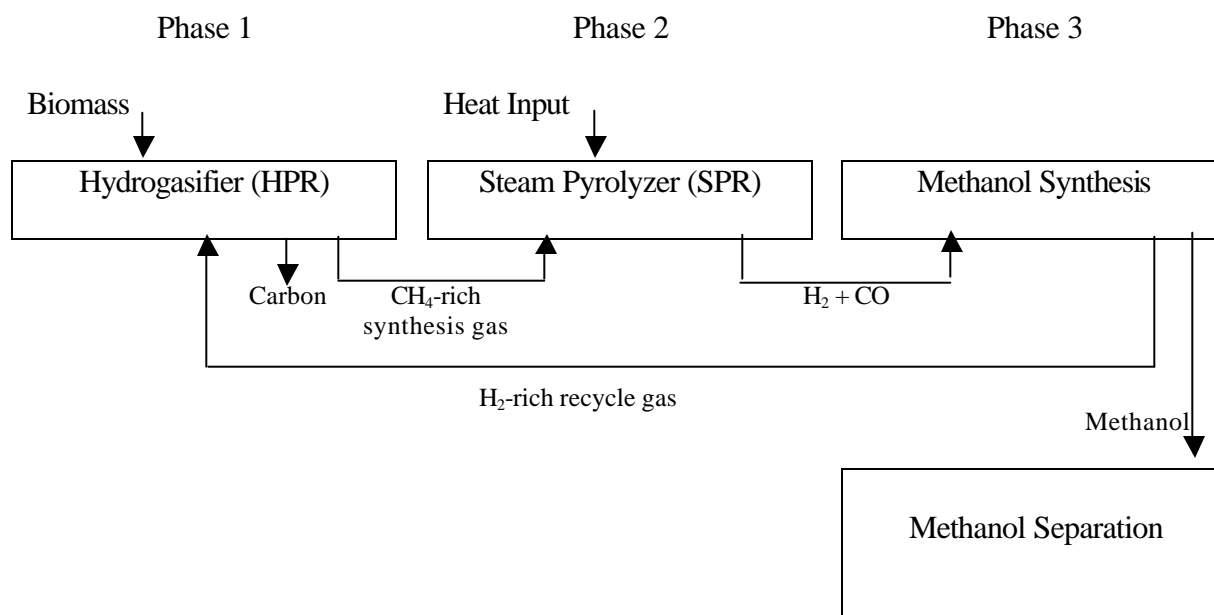
## 2. Hynol Process Description

### 2.1 Technical Description

The Hynol Process originated at Brookhaven National Laboratory as a method for increasing the yield of fuel from conversion of biomass. 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 methanol, a liquid fuel that can be used for transportation, industrial processes, electrical power generation, and military needs.

The process involves three phases (Figure 2-1):

1. Reaction of biomass in a hydrogasifier, also referred to as a hydropyrolizer (HPR).
2. Steam pyrolization 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 pyrolizer.



**Figure 2-1. Hynol Process flow.**

The basic Hynol Process consists of two reactions: (1) hydrogenation (or hydrolysis) of the carbonaceous feedstock to produce methane, followed by (2) the endothermic reaction of methane with steam to produce hydrogen and CO (steam pyrolysis). For methanol production, the carbon monoxide formed in the steam pyrolysis step is catalytically combined with the hydrogen in a third step 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<sub>2</sub>-rich process gas at 30 atm and 800 °C. 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<sub>2</sub>, and 20 mole % CH<sub>4</sub>. Nitrogen that comes from the feedstock forms inert N<sub>2</sub> in the process gas and is taken into account in the calculation of equilibrium gas composition. The conversion of the carbon in biomass feedstock in the HPR is 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 or sequestered. Reactions (2) and (3) are endothermic and require additional energy input to the gasifier. This is why the 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, the 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 provides sufficient heat for reactions (2) and (3).

Before entering the SPR, the process gas from the HPR of the Hynol Process usually needs to be cleaned up to remove particulate and impurities that may contaminate catalysts in the subsequent reaction steps. Conventional hot gas cleanup methods can be used for this purpose. Feed natural gas 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 methane feed react with steam to form CO and H<sub>2</sub>. The steam reforming can be described by two independent reactions:



The MSR is a conventional methanol synthesis reactor using a copper-based low-pressure catalyst. The reactions are performed at 30 atm and 1,000 °C. 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<sub>2</sub> 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:

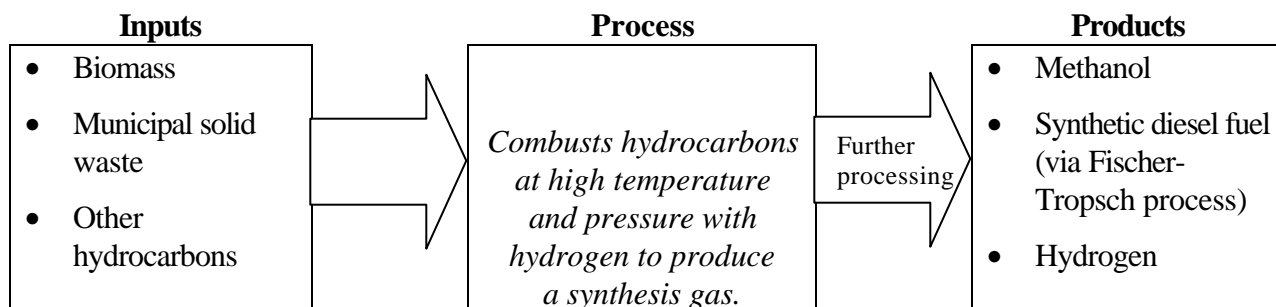


The methanol synthesis is performed at 30 atm and 260 °C. However, higher MSR pressures (up to 100 atm) are also feasible. The MSR reactions are highly exothermic, so the released process heat can be extracted from the MSR and used to dry the biomass feedstock. Methanol is separated from water in a condenser and fractionated to produce concentrated methanol. 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.

## 2.2 Applications

As noted earlier, the objective of CE-CERT's research involving the Hynol Process has been production of renewable methanol. However, the versatility of the process (Figure 2-2) is one potential advantage. This would enable a commercial Hynol facility to produce multiple energy or chemical products, or to be reconfigured in response to changing market conditions.



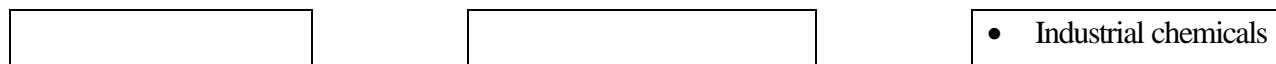


Figure 2-2. Potential products of the Hynol Process.

### 2.3 Economics of the Hynol Process

CE-CERT has not yet performed research into the economics of the Hynol Process. Previous research, however, has concluded that a commercial-scale, optimized Hynol system could produce methanol at a cost competitive with gasoline (Borgwardt, 1997b; Dong and Steinberg, 1997). Estimates (in 1997 dollars) are that Hynol can produce a gallon of methanol for between 41 and 46 cents. By comparison, the cost of producing a gallon of gasoline is 60 cents (Borgwardt, 1997b). Because the specific energy of gasoline is greater than that of hydrogen, this would make Hynol-derived methanol less economical than gasoline for use in an internal-combustion engine. Used in a fuel cell, however, the methanol would prove to be lower in cost because of the differential in efficiency. This analysis did not contemplate fuel cells that use gasoline as a hydrogen source.

These estimates are based on paper studies, costs of comparable technologies, and the limited results of bench-scale research.

### **3. Previous Research and Development**

#### **3.1 Inventors and Patents**

The Hynol Process was invented by Meyer H. Steinberg of Brookhaven National Laboratory and Yuanji Dong of Arcadis Geraghty & Miller (formerly Acurex Environmental Corporation). They are listed as the inventors on two U.S. patents relevant to the process:

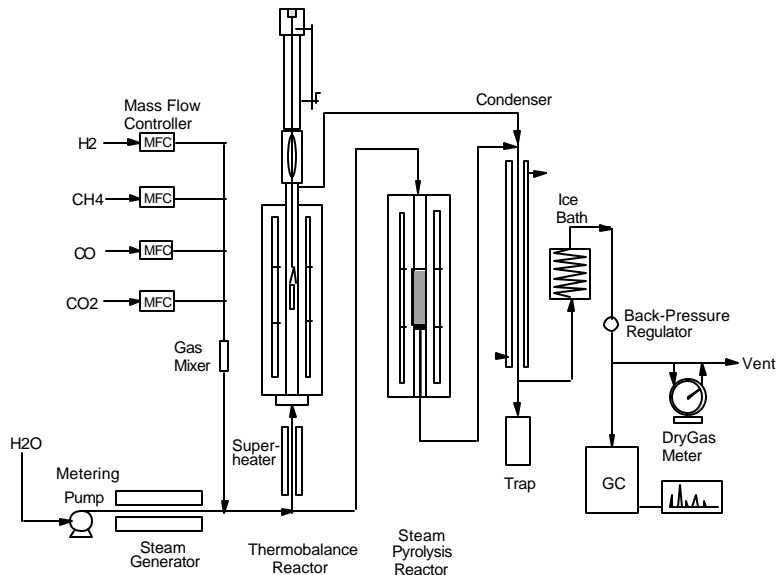
- 5,344,848, Process and Apparatus for the Production of Methanol from Condensed Carbonaceous Material (1994), Re. 35,377 (1996).
- 5,767,168, Method for Converting Natural Gas and Carbon Dioxide to Methanol and Reducing CO<sub>2</sub> Emissions (1998)

To the best of CE-CERT's knowledge, no new patents on the Hynol Process or improvements have been issued or applied for since then.

#### **3.2 Bench-Scale Research**

The U.S. EPA sponsored research by Arcadis Geraghty & Miller (formerly Acurex Environmental Corp.) to perform bench-scale Hynol research in the early 1990s. A thermobalance reactor (TBR) and a steam reforming reactor (SPR) were installed in the laboratory. The reactor was connected to the gas feed system and the downstream equipment for separate testing of biomass gasification and steam reforming. The reactors were mounted to a free-standing safety barricade. A computer and instrumentation were provided to ensure that tests could be conducted in a safe and reliable manner. Figure 3-1 shows the laboratory design.

The TBR was used to evaluate the reactivity of biomass in Hynol gasification. It was electrically heated and consists of a 1.38-in ID stainless steel reactor pipe, a 12-in OD pressure vessel, and a topwork housing a transducer for measuring the weight loss of a sample during reaction. A pulley assembly was used to raise and lower a sample basket between the topwork and the reaction zone. The TBR provided automatic recording of weight loss of the sample as a function of reaction time. The SPR was an integrated fixed-bed reactor used to evaluate the catalyst activity in steam reforming, consisting of a 0.82-in ID reactor tube and a 12-inch stainless steel, pressure-retaining vessel. The reactor was 4 feet long and was electrically heated by a separately controlled three-zone heater. A perforated-plate support was installed to position catalyst sample in the middle section of the reactor. The feed gas mixture entered the top of the reactor and was preheated in the top heater zone prior to contacting the catalysts. Both reactors could operate up to 50 atm and 1000 °C. Mass flow controllers were used to control the flow rates of H<sub>2</sub>, CH<sub>4</sub>, CO, and CO<sub>2</sub> from individual gas cylinders to simulate the feed gas composition of Hynol operating conditions. The steam was added to the feed gas from a steam generator fed with distilled water by a metering pump. The reactor exit gas was cooled in a condenser followed by an ice-bath to remove moisture, and then depressurized via a back-pressure regulator before being vented to atmosphere. The flow rate and composition of the product gas were measured by a dry gas meter and a gas chromatography, respectively.



**Figure 3-1. Bench-scale Hynol facility.**

In the TBR testing, the reactivities of poplar wood and pressed switchgrass were evaluated. More than a hundred test runs were conducted. It was observed that the hydrogasification under Hynol operating conditions involved a rapid devolatilization and pyrolysis reaction of the volatile matter in biomass and a slow reaction of residual carbon with the process gas. The rapid-reaction was found to be essentially completed in less than 0.2 to 0.3 minutes, contributing most of the biomass conversion. A three-parameter kinetic model was developed to correlate the experimental sample weight loss and quantitatively express gasification rates and biomass conversion as a function of reaction time. The effects of particle size, gas velocity, system pressure, reaction temperature, and feed gas composition on biomass gasification behavior were investigated. The study showed that nearly 86% of 1/8-inch poplar particles and 90% of sawdust could be converted into gas products in 60 minutes. Reaction temperature and particle size strongly affected the gasification rate and biomass conversion. The conversion was proportional to the partial pressure of hydrogen and steam in the feed gas. The comparison of the compositions between the chars after 20 minutes and 150 minutes of gasification showed that there was virtually no further conversion of hydrogen and oxygen in the char after 20 minutes. The additional biomass conversion resulted from the reaction of carbon in the residual char with the process gas.

In the SPR testing, a number of test runs were made under the conditions simulating the steam reforming step of the Hynol process. To quantitatively interpret the experimental data, a kinetic model was developed based on the first order reaction with respect to the partial pressure of methane in the feed gas as well as the consideration of the increase in total gas moles as the reaction proceeds. The intrinsic reaction rates were measured at different reaction temperatures using catalyst powders in the size less than 0.1 mm crushed from a commercially available Ni-catalyst. An activation energy of 28 kcal/mol was determined from Arrhenius plots. The effectiveness of the commercial-size catalyst pellets used in industrial steam reformers was evaluated, showing a strong restriction of pore diffusion within the pellets

upon the overall reaction rate. A steam-to-carbon ratio of 2.0 in the feed gas was found to be appropriate to avoid carbon deposition on the catalyst under the Hynol operating conditions. The testing has proved that the commercially available Ni-catalyst was suitable for methane steam reaction under the Hynol process conditions.

In 1992, a panel of fuel production experts from the Department of Energy, the Gas Research Institute, the Oak Ridge National Laboratory, the Massachusetts Institute of Technology, Tennessee Valley Authority, and other organizations conducted a peer review of the Hynol Process and confirmed the potential for the process to produce large quantity of methanol from biomass at prices competitive with gasoline and with low net carbon dioxide emissions. The EPA proposed to demonstrate methanol production from biomass using the Hynol process. The California Energy Commission and the South Coast Air Quality Management District (SCAQMD) supported the demonstration project. The project site was selected at the University of California, Riverside, College of Engineering-Center for Environmental Research and Technology (CE-CERT). The EPA obtained funding from the Department of Defense through the Strategic Environmental Research and Development Program (SERDP). The overall goals of the project are to demonstrate the performance of a pilot-scale integrated unit with a biomass capacity of 50 lb/hr and generate design, construction, and operating data for plant scale-up.

### **3.3 Pilot-Scale Facility Design**

Under contract with the U.S. EPA, Arcadis Geraghty & Miller prepared a design for a pilot-scale Hynol facility (Unnasch, 1996). The EPA peer-reviewed and accepted this design. Under a separate agreement, the EPA provided CE-CERT with this design and funds to construct it. Numerous flaws in the design, as well as materials problems, were found during construction and start-up operations. Many of these problems were serious and required significant re-engineering by CE-CERT. These problems and their solutions are documented in a report by CE-CERT to the EPA titled *Evaluation of a Process to Convert Biomass to Methanol Fuel* (Norbeck and Johnson, 2000). This report still is in draft form and will be made final during August 2000. It documents modifications and improvements to the following systems, components, and processes:

- Hydrolysis reactor refractory material.
- Burner management system.
- Secondary air system.
- Low-pressure igniter.
- Burner vessel.
- Biomass feed system conveyor.
- Biomass feed system overflow chutes.
- Feed system storage containers.
- Electrical controls.
- Gas supply and measurement system.
- Steam flow metering.
- Nitrogen pulse heater.
- Bed height measurement methodology.
- Flow calculation methodology.

- Cooling system.
- Solenoid valves.
- Exit flare stack.
- Heat exchanger.
- Sample system.

These modifications are described in greater detail in Section 4. We expect that when the Norbeck and Johnson report is submitted to and accepted by the U.S. EPA, the previous document either will be modified or withdrawn.

## 4. CE-CERT Research on the Hynol Process

### 4.1 Introduction

The current project called for CE-CERT to construct and operate a pilot-scale facility for Hynol research and development. Original objectives of the program were to:

- Demonstrate performance of high-pressure fluidized bed hydrogasifier to produce synthesis gas.
- Demonstrate a maximum carbon conversion under simulated optimum recycle gas conditions of a steam/carbon ratio between 2.5 and 3.5 in the steam pyrolysis reactor (SPR).
- Demonstrate the hydrogen pyrolysis reactor (HPR) system capability to operate without external energy sources other than feed stream enthalpy.
- Feed and gasify biomass in the HPR without agglomeration problems.
- Generate data for scale-up of an HPR to 10 tons/day.
- Develop a biomass feed system and test its durability.
- Demonstrate alkali metal adsorbing materials that successfully mitigate gasifier problems.
- Test a hot gas cleanup system sustainable for the HPR system.

Figures 4-1 and 4-2 show schematic diagrams of the facility as built and modified. The figures also indicate the locations of thermocouples and sensors installed in the system to monitor its operations.

CE-CERT constructed the system according to the EPA design (Unnasch, 1996). Before operation could begin, significant redesign of many components and subsystems was necessary to assure proper, safe function. These modifications were designed, implemented, and tested before process research could begin.

### 4.2 Reactor Design and Construction

The following modifications to design specifications and construction procedures were made. These modifications should be taken into account for any subsequent development of pilot-scale or larger Hynol facilities. It is expected that these changes, which have been provided in a report to the U.S. EPA, will be appended to the EPA's existing document on Hynol facility construction (Unnasch, 1996) or used as a basis for revising that document.

**Refractory.** The original plan called for curing of the refractory material on-site rather than at the factory. This required long-running operation of the heater and significant staff time. Factory-curing would be more cost-effective. Also, the original specifications for the refractory material were deficient. The refractory was delivered damaged, and the vessel flange was cracked. CE-CERT had to return several pieces for remanufacture or repair.

**Feed system.** The original feed system contained no mechanism for determining mass delivered. This would have made it impossible to calculate mass balances and system efficiency. Additionally, the system was subject to bridging. CE-CERT completely redesigned the feed system and developed mechanisms for accurately measuring the mass provided to the reactor, as required by the CE-CERT testing plan.

**Burner system.** The original burner system had many design flaws. The burner was designed to preheat the reactor, filter, and heat exchanger sections on start-up, but it was not originally designed to operate in a high-pressure environment. As a result, the burner flame frequently was extinguished. CE-CERT redesigned the burner system for adequate operation. The secondary air injection system also had to be redesigned to prevent the flow of air from carving a hole in the refractory system.

**Gas preheater.** A nitrogen pulse heater and a hot gas preheater purge, used to clean the ceramic filter hourly, were not included in the original design. CE-CERT designed and implemented this system.

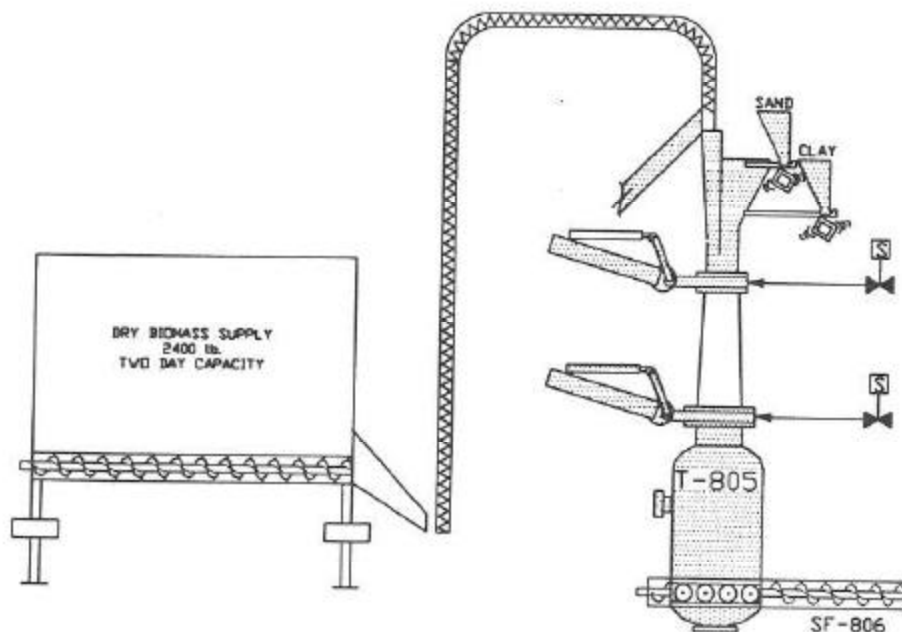


Figure 4-1. Hynol biomass feed system.

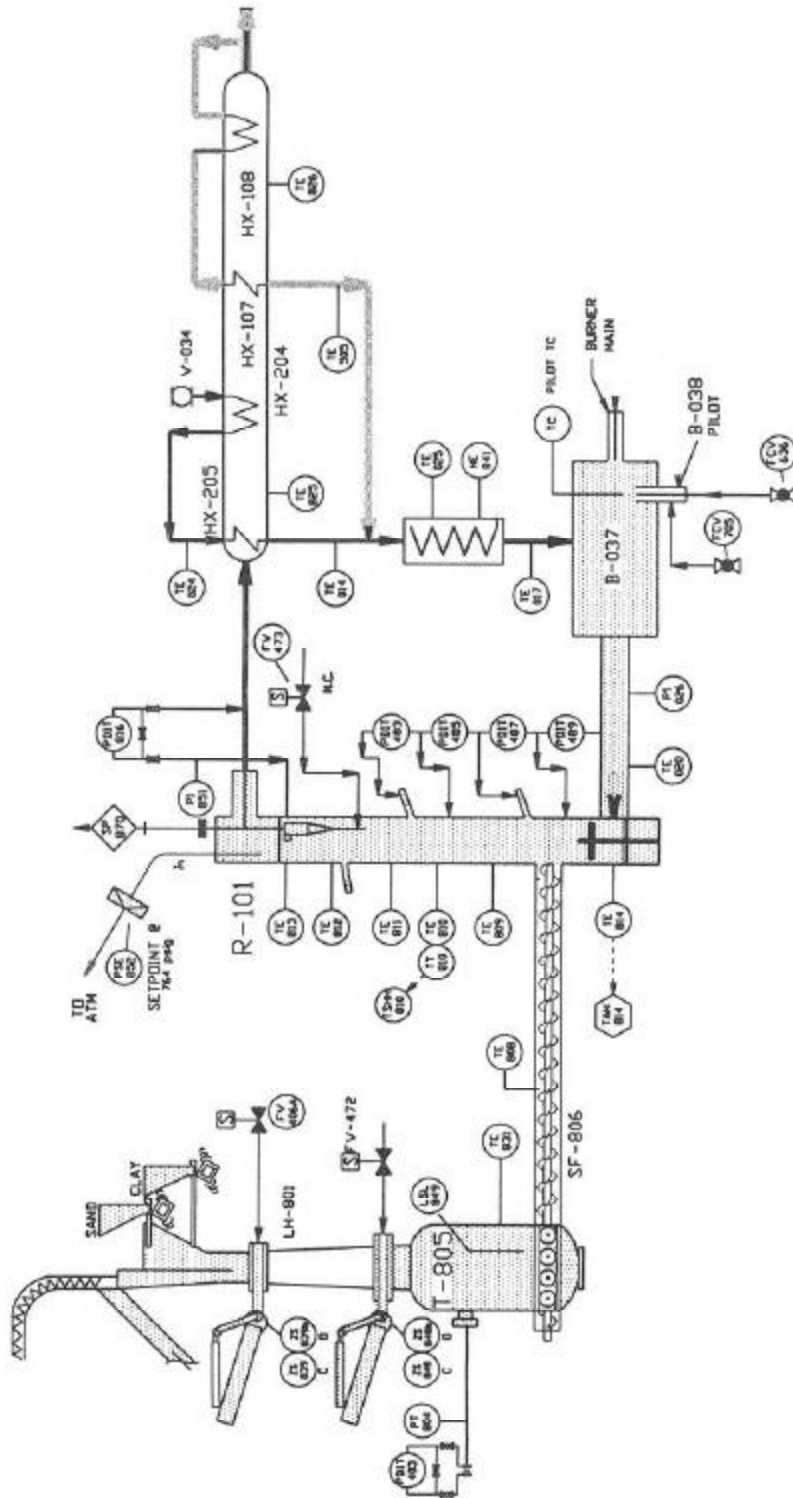


Figure 4-2. Hynol reactor.

**Cooling system.** A cooling system also was required for safe, sustained operation. The original design did not have a cooling system.

**Gas flow sensors.** The original gas flow sensors were inadequate and would have impaired the accuracy of flow measurements. Also, steel was used as the material for orifice flanges, making them subject to rust. CE-CERT recalibrated the sensors and plated the flanges with nickel to prevent rusting.

**Steam flow.** The original design for steam injection caused condensation inside the vessel. Originally, an orifice type flow meter was to be used for steam flow metering. 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. CE-CERT used a 500 ml burette at the inlet to the steam pump and to spot-check the flow of the steam pump during testing.

**Heat exchangers.** An external heat exchanger was not part of the original design. The internal heat exchanger was not sealed, allowing mixing of input and output gases. Spring hangers were sized incorrectly and had to be replaced. CE-CERT designed and implemented an external heat exchanger. The heat exchanger was redesigned using new materials, and spring hangers were replaced.

**Water removal.** The original design did not address water removal. CE-CERT is continuing to study this issue and making appropriate modifications.

### **4.3 Reactor Operation**

CE-CERT developed standard operating procedures, a process control system, and a sampling plan for the pilot-scale reactor. Numerous tests of subsystems, components, and the entire system were conducted over the course of construction and modification. These tests turned up other challenges that had to be overcome to enable operation of the facility as designed.

The full system was operated successfully for the first time on January 5, 2000. The facility achieved and held its operating temperature, biomass and gases were introduced, and fluidization and gasification were recorded. Steady-state gasification was not achieved, and we detected a troubling loss of temperature when air was withheld. Considerable further research is needed, as described in Section 5.

### **4.4 Preliminary Results**

The major accomplishments of the program so far have been the development of an operational pilot-scale facility and procedures for its operation and data collection. Limited data collection has taken place, and we are only beginning to be able to characterize the process and its efficiency.

Based on the limited results obtained to date and previous research conducted by others (see Appendix), CE-CERT has modeled the performance of the facility. Table 4-1 summarizes the modeled performance from CE-CERT and other research.

**Table 4-1. Modeled Performance of Hynol Process.**

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	Hynol UC Riverside Test #4 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 **
H <sub>2</sub>	95% **	69.9 %**
CH <sub>4</sub>	0% **	1.80 %**
CO	0% **	8.95 %**
CO <sub>2</sub>	0% **	3.90 %**
H <sub>2</sub> O	0% **	0.0 %**
N <sub>2</sub>	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 *
H <sub>2</sub> O	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)	.432	0.459
Hydrogasification Products	1.99 kmol/hr (21kg/hr) **	3.056 kmol/hr (45 kg/hr)**
CH <sub>4</sub>	10.5% **	19.1% **
CO <sub>2</sub>	2.76% **	6.3 % **
CO	14.0% **	12.1% **
H <sub>2</sub>	85.8% **	37.1% **
N <sub>2</sub>	3.27% **	5.9 % **
H <sub>2</sub> O	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 *
Bed Material	InvestoCast 50	Sand *
Particle Diameter	0.34 mm (0.013in)	n/a
Volume Added	15 L	n/a
Composition	52% SiO <sub>2</sub> , 42% Al <sub>2</sub> O <sub>3</sub>	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.

## **5. Research Needs**

### **5.1 Hynol Process Activities**

The long process of developing the Hynol facility is largely complete. Although we anticipate further modifications as the research program progresses, we expect now to be able to concentrate on studying and developing the process for methanol production.

CE-CERT is unusual among University of California research laboratories in that we have a full-time, permanent research staff in addition to faculty, graduate students, and postdoctoral researchers. Recently, a senior development engineer with expertise in gasification and fluidized beds has joined CE-CERT's staff. It is anticipated that he will play a key role in further research.

CE-CERT also is unusual in the high degree of industry involvement in its research. More than 90% of CE-CERT's annual budget is derived from research contracts and grants, including a significant portion sponsored by industry. We are equipped to collaborate closely with industry (even going so far as having industry sponsors' researchers work in our laboratories alongside our personnel), and we have well established mechanisms for the use of intellectual property and the licensing of inventions.

### **5.2 CE-CERT's Vision for Sustainable Transportation Research**

CE-CERT is an integrated research laboratory with projects spanning the full range of transportation issues, from fuels to energy conversion to emission controls to atmospheric impacts to public policy. The Hynol research is a cornerstone of a vision for sustainable transportation research that CE-CERT is developing. We are optimistic that a multi-year program with significant involvement of industry, University of California resources, and government agencies can be assembled.

The proposed California Sustainable Transportation Institute will take a systems approach to transportation issues, encompassing energy demand, energy sources, transportation and environmental strategy, land-use strategies, and the full environmental consequences of transportation. The program also will study individual and societal implications of transportation technologies and strategies: the personal choices, cultural evolutions, and educational approaches that determine what approaches succeed or fail in the market. Although the Institute necessarily must focus intensely on technology and industry interaction, the program also will comprise interdisciplinary research and education involving engineering, the physical sciences, and the social sciences. Significant private and non-state funding would come from companies and agencies involved with energy, the environment, agriculture, and waste management.

Transportation accounts for more than one-quarter of all energy consumption in the United States, and fossil fuels have provided more than 95% of all transportation energy throughout the 20<sup>th</sup> Century (USDOE, 1998). California alone had 22.26 million automobiles and consumed nearly 13.5 billion gallons of gasoline in 1997, the latest year for which statistics are available (CEC, 1999). Significant increases in the number of vehicles and miles driven, both domestically and worldwide, will put

additional pressure on petroleum supplies and will continue to contribute to air pollution and global climate change (PCSD, 1999).

The President's Council on Sustainable Development concluded that if the United States continues to operate its transportation system without changes, growth in energy use and transportation demand will overwhelm any efficiency improvements derived from new technologies (PCSD, 1999). This will result in significant environmental and economic deterioration. The Council's recommendations include new approaches and technologies to reduce transportation demand as well as new technologies for reducing dependence on fossil fuels, increasing U.S. energy independence, and reducing emissions of pollutants and greenhouse gases.

California and the nation have a compelling need to take a systems approach toward development of an environmentally and economically sustainable transportation system. Sustainable transportation would be based on renewable rather than fossil energy, and it should improve efficiency to reduce emissions of criteria pollutants, toxic air contaminants, and greenhouse gases. It would assure adequate mobility for people and products. It would build on existing industry and infrastructure in California, and it should encourage the development of new transportation and energy conversion technologies in the state. Sustainable transportation planning also can provide a framework for other important planning and development in the state. Population growth, land use strategies, and economic development are intertwined with transportation availability and cost. Wise planning for transportation will improve overall planning for California.

The Institute's research agenda will evolve as promising technologies are developed, as industrial and academic partners join, and as interdisciplinary research and education programs provide new perspectives. The following list serves as a starting point for the research agenda.

- **Fuel production and distribution.** Replacing the 97% of transportation energy dependent on fossil fuels today will require innovation in the identification and development of renewable feedstocks. Agricultural crops, agricultural waste, other solid waste, solar energy, and other sources will be investigated. A high priority is biomass-to-fuel conversion. Processes for converting feedstocks into usable transportation fuels will be developed, demonstrated, and evaluated. At the same time, however, we should not turn our back on carbon management strategies, which would remove carbon dioxide, an important greenhouse gas, from the ecosystem and provide, at least for the short term, a "sustainable" way of continuing to use cost-effective fossil fuels.
- **Energy storage, energy conversion, and propulsion.** The fuels or energy derived from renewable resources are likely to require modifications to distribution systems, refueling infrastructure, and engines or energy conversion devices aboard the vehicles themselves. The development of engines (or other energy conversion devices) and fuels must go hand-in-hand.
- **Transportation system design and control.** As noted by the President's Council on Sustainable Development, innovative ways to control transportation demand are essential to reducing the environmental and energy impacts of transportation. At UCR, the CE-CERT demonstration of the IntelliShare electric vehicle system is one example of such an innovative transportation approach. Research and analysis of issues involving development, land use, and infrastructure also would be conducted in this category.

- **Environmental impacts.** The development and use of new fuels, new engines, and new transportation systems can have unexpected consequences. The gasoline additive MTBE, for example, made a strong contribution to reducing air pollution but resulted in groundwater contamination. California's refineries spent hundreds of millions of dollars modifying systems to add MTBE, and now are spending millions more to eliminate it. The multimedia environmental impacts of fuel or energy production and consumption must be well understood to prevent costly mistakes in the development of future transportation technologies. Experimental analysis and modeling studies will answer these critical questions.
- **Economic impacts.** The externalities of any new approach must be evaluated in an objective way to assure that finite resources are applied in the most beneficial way. The incremental cost of a new fuel or a new propulsion system is only part of the question. The economic implications of environmental protection and sustainability are one issue to be explored. Another is the potential economic impact of alternative fuel use on California, where hundreds of thousands of jobs and billions of dollars in economic activity depend on traditional energy production.
- **Social implications.** Public acceptance of new technologies and approaches is critical to success, but is far from assured. As new technologies or transportation management systems are developed, determining how to move from the laboratory or small-scale demonstration to the mainstream is essential. This requires an understanding of public expectations regarding transportation and consumers' economic and social priorities. Additionally, this research area should include studies of educational approaches to make consumers understand the connection between their personal choices and macro-scale economic and environmental issues.
- **Policy implications.** As CE-CERT has demonstrated numerous times, the most successful regulatory strategies are those that make economic sense and have the "buy-in" of the regulated community. The viewpoints of other stakeholders also is a critical factor in decision-making — for example, environmental justice for low-income communities has been a factor in decisions at the South Coast Air Quality Management District in recent years. Astute, realistic analysis of what can and should be achieved will require interdisciplinary collaborations among engineers, physical scientists, and social scientists, as well as participation by industry and government agencies.

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