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DEVELOPMENT OF HIGH TEMPERATURE TURBINE SUBSYSTEM TECHNOLOGY TO A "TECHNOLOGY READINESS STATUS" PHASE I

PROGRESS REPORT FOR JUNE 1976

A. CARUVANA

GENERAL ELECTRIC CO.
GAS TURBINE DIVISION
1 RIVER ROAD
SCHENECTADY, N.Y. 12345

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ABSTRACT

Primary emphasis was placed on the preparation of engineering documents to provide the basis for study activities by the many contributors on the interrelated tasks. In parallel the various work statements, subcontracts and Project Funding Authorizations were generated.

Preliminary information was generated on overall plant cycle definition, heat balance, performance predictions, gas turbine component sizing and aerodynamic data. The coal handling, drying and storage systems were sized and utility requirements calculated. A preliminary rating of an induced draft cooling tower was prepared.

A preliminary review was conducted of Low Temperature Gas Cleanup Systems. The review encompassed various proprietary acid gas removal systems and two particulate and tar removal schemes.

The Preliminary System specifies a Benfield Acid Gas Removal Unit and Claus sulfur recovery plant preceded by raw gas quench and followed by a clean gas saturator.

Based on a combined cycle configuration with an integrated fixed-bed gasifier, cycle conditions were established for the three reference turbine subsystem designs. Gas flow path sizing, air foil shapes and pitchline velocity distributions were then calculated.

Test plans were established for mechanical and physical properties testing of materials identified for use in the preliminary design of water cooled hardware. Also to be evaluated is the behavior of bond joints for various combinations of materials.

Advance work was started on the design of the Hot Gas Path Test Stand.

Combustor design work will be based on a product low-BTU coal gas composition based on the Illinois No. 6.

REPORTING CATEGORY I

TASK 1 - PREPARE OPDD FOR 1) COAL GAS COMBINED CYCLE PLANT AND 2) COAL LIQUID COMBINED CYCLE PLANT

WORK ACCOMPLISHED

Activity during this report period has been primarily directed toward preparation of the engineering documents which provide the basis for study activities by the many contributors, and also orgainzation of the work scopes.

Preliminary cycle definition, heat balance, and performance calculations were made for the fixed-bed low-Btu gasification plant (Case A) and the coal-derived liquid plant (Case C).

Preliminary sizing of the gas turbine components has been completed based on present available information. Power Plant Engineering preliminary requirements have been identified. Preliminary aerodynamic information on compressor and turbine components was established and used in cycle calculations.

A preliminary design of the coal handling, drying, and storage systems was developed. Equipment was sized and utility requirements were calculated. The preliminary design data and utility requirements were summarized.

A preliminary rating of an induced draft cooling tower was prepared based on estimated heat rejection from the power island and estimated heat rejection from the gas cleanup system. Utility requirements were calculated.

SYSTEM CONFIGURATION AND DEFINITION ACTIONS

In order to establish a basis for system development, certain basic decisions were made during this report period including the following:

1. Coal Specifications

   Agreement was reached with G. Manning to use the coal specification for Illinois No. 6 coal which was used in the ECAS study. This coal specification replaces the RFP (49-18)-1806 specification and permits use of favorable heating values.

2. System Configuration

The fuels plant for Case A (fixed bed) has been defined to contain 14 gasifiers. Two gas turbines each developing approximately 187 MW are used on the topping cycle and one steam turbine developing approximately 156 MW is used for cycle bottoming.

3. Heat Rejection Conditions

The environmental basis for heat rejection by forced draft wet cooling towers was defined as Condenser pressure 2.5 inches of Mercury, Dry Bulb temperature of 59°F, Relative Humidity of 60 percent, Range of 30°F, Approach of 20°F. In addition the system has been matched to the yearly conditions of the Chicago, Illinois area.

4. Fuels Plant Lower Temperature

A preliminary economic analysis was made to establish the temperature above which the overall plant should be capable of 100 percent rated power output. This study showed that 40°F represents this temperature limit and at this temperature the fuels plant should be sized to accomodate 105 percent of rated (59°F, 60 percent R.H.) fuel flow through the gas clean up system.

5. Optimization Of Steam/Air Blast Conditions

As a result of gasifier calculations based on a computer analysis developed for the fixed bed type gasifier, optimization studies show that a ratio of steam to air blast of 0.198 should be used for continuing studies of Case A.

A preliminary review of Low Temperature Gas Cleanup Systems (LTGCUS) has been completed to produce a clean gas from an air-blown fixed-bed coal gasifier, suitable for use as a gas turbine fuel. The capacity of the combined-cycle power plant under consideration is 530 MW for which about 200 tons/hr of coal will be fed to the gasifier.

The review results are presented in two sections. Section I cover the review of two particulate and tar removal schemes and various proprietary acid gas removal systems. Section II presents preliminary data for a gas cleanup system including a Benfield Acid Gas Removal Unit and Claus Plant to be used in the Preliminary System.

I. LOW TEMPERATURE GAS CLEANUP SYSTEMS - A PRELIMINARY REVIEW

A low temperature gas cleanup system consists of a quench unit where the raw gas is cooled and tar, oil and solid particulates are removed, and acid gas removal unit in which H_2S and other sulfur compounds are removed, and a sulfur recovery unit where sulfur compounds are converted into elemental sulful. Afterwards, the clean gas is saturated with water and recovered oil before it goes to the turbine combustor.

RAW GAS QUENCH

In the raw gas quench unit the hot raw gas from the gasifier is ultimately cooled to a temperature suitable as a feed to the acid gas removal unit. The hot gas is cooled by quenching with either water or oil in a venturi-type mixing system. The cooled gas is contacted with water or oil in a shed-deck scrubbing column. In this column, liquid flowing counter current to the gas scrubs out solid particulates, oil and tar droplets from the rising gas stream. The tar, oil, water and solids then can be recovered in a vessel.

For improved overall process thermal efficiency, it is desirable to recover the heat from the quench unit as steam at the highest level. For this reason, preliminary concepts of two raw gas quench systems were developed. In one, water is used as the quench liquid. And in the second, both oil and water are used. The use of oil in the second case permits generation of 600 to 800 psig steam but requires much additional equipment for the oil recovery system. Moreover, in addition to the oil quench system, there must be a secondary water quench and scrubbing system. A preliminary economic review of these two systems indicates that a single water quench system is preferable.

ACID GAS REMOVAL

The raw gas from the quench unit will contain H_2S, COS and NH_3 along with other components. Depending on the end use of the clean gas the removal requirements of the acid gas system are defined. In this case the clean product gas will be used as fuel for a gas turbine. The gas cleanup requirement has been defined.

SULFUR REMOVAL

To meet the overall SO_2 emission requirement of 1.2 pounds of SO_2/MMBTU of coal feed, about 90 percent removal of the hydrogen sulfide is converted to elemental sulfur. This also assumes that no carbonyl sulfide is removed in the acid gas removal process.

CARBON DIOXIDE RECOVERY

Since the cleaned gas will be used in a gas turbine, it is desirable to leave as much of the carbon dioxide in the gas as is feasible. Therefore, a high selectivity for the preferential removal of hydrogen sulfide over carbon dioxide is desirable.

HYDROCARBONS RECOVERY

The loss of hydrocarbons in the gas cleanup step should be minimized in order to maintain a high overall plant thermal efficiency and to reduce the possiblity of product sulfur degradation in a Claus sulfur unit.

AMONIA REMOVAL

To meet the overall NO_x emission requirement of 0.7 pounds NO_x/MMBTU it is not necessary to remove any of the ammonia from the raw gas. However, it is desirable to limit the removal of ammonia with the acid gas in order to avoid the problem of burning ammonia in a Claus unit.

ACID GAS REMOVAL PROCESSES

There are several commercially proven processes which can be used to clean the raw gas. Based on past experience several processes have been selected for further evaluation. Their distinquishing characteristics are tabulated in Table 1.

ALKAZID

The process utilizes an alkaline salt solution of an organic compound for recovering dydrogen sulfide from the gas.

HOT POTASSIUM CARBONATE

The Hot Potassium Carbonate process meets the general requirements for this project.

SELEXOL

The Selexol process has been used for hydrogen sulfide recovery in other coal gasification studies. The process utilizes an organic solvent and can be tailored to meet the general requirements for this project.

STRETFORD

The Stretford process is different from the previously described processes in that it converts hydrogen sulfide directly to elemental sulfur. The process can be applied directly on the raw gas from quench and eliminates the need for a Claus conversion unit. Or, alternately, the process can be applied to the acid gas stream produced in the regenerator steps of the other processes in lieu of a Claus conversion unit.

SULFUR RECOVERY

The sour gas that will be produced in any of the acid gas removal processes, except Stretford mentioned above, will produce a high H_2S concentrated stream, and can economically be processed in a Claus sulfur unit. The requirement of 95 percent H_2S conversion to elemental sulfur is not a problem but presence of NH_3 or hydrocarbon in the Claus plant feed requires special handling and hydrocarbons will contaminate the sulfur product.

Note: (1) May be designed to operate at 300 to 400 psia.

TABLE 1

NAME	ALKAZID-DIK	HOT POT	STRETFORD	SELEXOL
Type of Solvent	Chemical	Chemical	Chemical	Physical
Normal Range of Treatment				
Pressure, psia	80-1000	100-1000	Insensitive 25 to 50 (1)	400-1000
Temperature, ^{o}F	60-200	150-300	90-130	40-80
Components Removed				
H_2S	Yes	Yes	Yes	Yes
Organic S Compounds	NO	COS & CS_2 (by Hydrolysis)	No	Yes
CO_2	Yes	Yes	No	Yes
Hydrocarbons	Small	No	No	Yes, Can Be Minimized
Ammonia	Very Little	Yes	Partially	Yes
H_2S Selectivity	Partial	Partial	Highly Selective	Partial
Limitations			High Sol'n Circulation Rates	Dehydrate Also
Commercial Status	Active	Active	Active	Active
Materials of Construction	Alloy Steel or Aluminum	Some Alloy Steel, Mostly CS	Mostly CS	Mostly CS
Satisfactory Feed to Claus	Yes	Yes, But Limited on NH_3 Conc	Not Required	Yes, But Limited on Hydrocarbon and NH_3 Conc
Refrigeration Req.	No	No	No	Yes
Reboil Heat Req	Low	Relatively High	No. But Some Steam for Melting Sulfur	Low
Sodium/Potassium Salt in Solvent	Yes	Yes	Yes	No

II. PRELIMINARY LTGCU SYSTEM

The gas cleanup system consists of three units - raw gas quench and saturator, Benfield acid gas removal, and Claus sulfur recovery.

RAW GAS QUENCH

In the raw gas quench unit, hot raw gas is cooled from 1075°F to 325°F by using water quench and scrubbing system. The gas is cooled first by saturating it with water in a venturi type quench fitting. It is then cooled further and scrubbed in a shed-deck column. The tar, solid particulates, and excess water are removed from the column bottom and are separated from the water in a settling tank. Tar and solids, except for one weight percent bleed, are recycled back to the gasifier. The water from the separator is pumped back to the quench fitting and the column after being cooled by heat exchange with BFW.

ACID GAS REMOVAL

The scrubbed gas from the quench column goes through a series of heat exchangers to preheat clean product gas, process condensates, along with naphtha and phenols to the saturator. The scrubbed gas, cooled to 170°F enters a Benfield absorber. The system has been rough designed by its licensor and most of the numbers given below have been received from them. The unit was designed to remove 90 percent of H_2S. In the Process, about 50 percent of COS is hydrolyzed to H_2S and removed. About 50 percent of CO_2 and most of NH_3 in the feed gas are also absorbed. Hydrocarbons loss is negligible in the absorber.

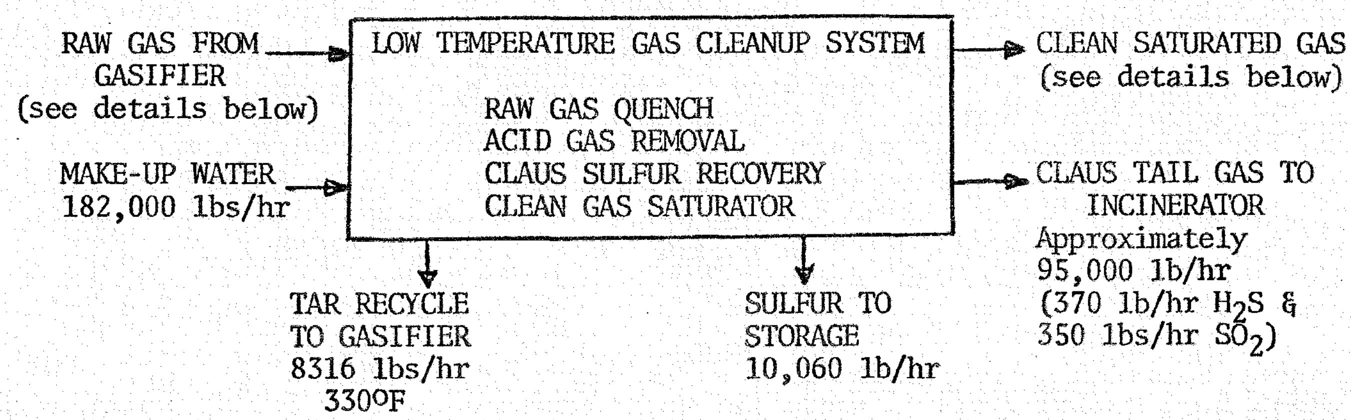
SULFUR RECOVERY

The sour gas from the Benfield regenerator goes to a Claus plant where 95 percent of H_2S removed is converted to elemental sulfur. The rough design data for this unit have been received from a process licensor.

MAJOR PROCESS STREAMS

The preliminary data of primary process streams in and out of the LTGCU System are summarized below.

PLANT CAPACITY=100%



COMPONENT	RAW GAS FROM GASIFIER	CLEAN SATURATED GAS TO COMBUSTOR
H_2 lb-mols/hr	6,853.8	6,806.0
N_2	20,461.2	20,319.4
CO	12,110.6	12,019.0
CO_2	2,876.0	1,429.0
H_2S	361.6	44.8
COS	27.6	13.6
NH_3	33.2	27.0
CH_4	2,139.4	2,125.0
C_2H_4	125.0	123.8
C_2H_6	175.6	173.8
Naphtha (1)	219.8	219.8
Tar (1)	39.6	-
Phenols (1)	27.4	27.4
TOTAL DRY	45,451.6	43,328.6
H_2O	6,001.4	16,719.4
TOTAL WET	51,453.0	60,048.0
Lbs/Hr	1,260,700.0	1,356,270.0
Temp/Pressure	1,075° F/ 340 psia (2)	316° F/ 305 psia

NOTE (1) No details available. Assume mol wt Naphtha = 145, Tar - 210. Phenols = 94.

(2) Estimate based on 304 psia at the clean gas saturator outlet.

WORK FORECAST

The work during July will include establishing the preliminary overall plant flow sheet, the preliminary system definition, and the clean gas specification. The power plant related control requirements will also be evaluated. Work will continue on the analysis of the low temperature gas cleanup systems. Besides the Benfield hot potassium carbonate system, the Eichmeyer hot potassium carbonate system, the Allied Chemicals Selexol process, and the BASF Alkazid process will be analyzed. An inquiry specification has also been prepared for the Stretford process which eliminates the need for a Claus recovery plant.

REPORTING CATEGORY II

TASK 2 - ESTABLISH BASELINE COMBINED CYCLE SYSTEM(S) FOR GAS AND LIQUID FUELS

Work on Task 2 is not scheduled until later in Phase 1.

REPORTING CATEGORY III

TASK 3 - ESTABLISH TWO REFERENCE 2600°F "GROWTH" TURBINE SUBSYSTEM DESIGNS

WORK ACCOMPLISHED

The cycle conditions were established for the three Task 3 reference turbine subsystem designs. The conditions were calculated for a combined cycle configuration with an integrated fixed-bed gasifier. The compressor pressure ratio was set at 16:1 with a flow rate of 700 lb/sec on a 59°F ISO day. The turbine firing temperature (downstream of the stage 1 nozzle) was set at 2600°F. Required turbine cooling flows were based upon past work conducted at General Electric on water cooling and air cooling. These cooling flows will be adjusted as they are refined throughout Phase 1. However, the basic cycle parameters affecting the gas turbine subsystem will not be altered during Phase I to reflect changes in other cycle components such as the gasifier, clean-up train, steam cycle, etc. It is necessary to "freeze" these parameters so that the design effort can proceed without time consuming iterations which would have little impact upon the turbine heat transfer and mechanical design. The turbine subsystem cycle design conditions are shown in Table 1.

First pass calculations were made for the gas flow path layout, airfoil shapes, and pitchline velocity distributions for the prime turbine subsystem design specified by the cycle conditions. The flow path was sized to provide conservative flow conditions throughout, resulting in a three stage turbine with the following energy split: stage 1-40%, stage 2-34%, and stage 3-26%. The stage 3 loading is light to facilitate growth of the gas path design to the 3000°F firing temperature. Most of the increased loading at higher firing temperatures would appear on the third stage.

TABLE 1

TURBINE SUBSYSTEM CYCLE DESIGN
CONDITIONS FOR TASK 3

	Prime	Backup 1	Backup 2
Combustor Outlet Flow (pps)	779	792	620*
Combustor Outlet Temp. (^{o}F)	2650	2650	2600*
Combustor Outlet Pres. (psia)	224.6	224.6	224.6*
Turbine Subsystem Cooling Flow (pps)			
Water and Steam	119	133	0
Air	14	3	153
Turbine Exhaust Flow (pps)	806	839	772
Turbine Exhaust Tem. (^{o}F)	1259	1253	1166
Turbine Exhaust Pres. (psia)	15.4	15.4	15.4
Net Gas Turbine Shaft Output (MW)	187	200	143

*Stage 1 bucket inlet conditions

The gas path layout for the backup turbine subsystem designs will be identical to the prime design even though the turbine flows will vary somewhat as shown in Table 1. It is not felt that the change in flow path, should separate ones be calculated for each cooling scheme, would effect the overall turbine subsystem design enough to warrant the increased calculations during the Phase 1 preliminary design. However, turbine efficiencies for the three designs will be calculated as if the flow path were optimized for each case. This will provide a more consistent basis for evaluating the three designs.

Mechanical design goals for bucket and nozzle life have been set for low-Btu gas and are shown in the following table.

	Base Load Life-Hours
Nozzles	
Stage 1	50,000
Stage 2	50,000
Stage 3	50,000
Buckets	
Stage 1	100,000
Stage 2	100,000
Stage 3	100,000

Planning and program implementation activities are nearing completion for all aspects of Task 3. Internal engineering documents have been established for defining group responsibilities and transmitting data between different functional groups within Gas Turbine Engineering and Manufacturing Department (GTE&MD). General Electric Aircraft Engine Business Group (AEBG) in Evendale, Ohio will be engaged to carry out the gas path heat transfer and mechanical design for the first and second stages of the steam cooled and air cooled backup designs. Discussions with AEBG regarding work scope, technical content, and programmatic aspects of the project are nearing completion.

Plans and schedules have been developed for several programs with the General Electric Materials and Processes Laboratory (M&P Lab). These programs involve the development of forming methods for 0.030 inch thick nozzle and bucket claddings, selection of high strength, high conductivity copper alloy for the nozzle and bucket substrate material, development of higher strength copper/A-286 bondlines, and the improvement of clad erosion/corrosion resistance. Other programs involve the investigation of fabrication processes to be applied to the second and third stage buckets.

Test plans have been established for the advance work concerning the acquisition of basic properties data for materials identified for use in water cooled hardware. Materials that have been identified for mechanical and physical properties testing are: skin materials - IN-617, IN-671, Hastelloy-S, and Nimonic 263; substrate materials - O.F.H.C. copper, O.D.S. copper, and Nickel 201; tube materials - Monel 400 and A-286; and spar material - A-286. The behavior of the bond joints under thermal and mechanical stresses and strains will also be evaluated for various bond combinations of the above materials. The materials for the test samples have been ordered and the O.F.H.C. copper, A-286, Monel 400, and IN-671 have been received. Several vendors have been contacted with regard to performing the materials tests.

WORK FORECAST

The turbine aerodynamics effort will be directed towards finalizing the blade row designs for the turbine subsystem preliminary design. Work will begin in almost all areas of turbine mechanical design including the nozzles, buckets, casings and wheels. Work will continue in process development and many of the test specimens will be made for the materials properties evaluations.

REPORTING CATEGORY IV

TASK 4 - IDENTIFY TOTAL PROGRAM RESEARCH AND TECHNOLOGY REQUIREMENTS FOR SYSTEMS USING COAL GAS AND LIQUID FUELS

WORK ACCOMPLISHED

Task objectives and schedules were established for Task 4. It is planned that all major areas of research and technology requirements will be identified by the end of October so that they can be included in the Phase 2 planning effort.

WORK FORECAST

Task 4 will be a continuous process throughout much of Phase 1 and as such no formal plans or milestones have been set for July.

REPORTING CATEGORY V

TASK 5 - DEVELOP PHASE 2 PROGRAM PLAN

WORK ACCOMPLISHED

The overall planning, schedules and program inplementation have been established for Task 5. The Phase 2 plan will address the research and development areas identified in Task 4. The topical report covering the Phase 2 program plan is scheduled to be completed by the end of December.

Advance work has started on the design of the Hot Gas Path Test Stand which is scheduled for fabrication during Phase 2 of the HTTT program. A specification for the design of the basic test stand was written and sent to several possible subcontractors for quotes. The test stand will be designed to accommodate approximately one-twelfth of the flow to be experienced by Phase 3 Technology Readiness Verification Test (TRVT) turbine. (ref. Table 2)

WORK FORECAST

Work on developing the Phase 2 program plan.

Work will continue on the Hot Gas Path Test Stand. A subcontrator will be identified for the test stand design. Turbine aerodynamic work will be

TABLE 2

TURBINE SUBSYSTEM PRELIMINARY CYCLE DESIGN CONDITIONS FOR (TRVT) TURBINE

	Firing Temperature 2600°F	Firing Temperature 2800°F
Combustor Outlet Flow (pps)	674	689
Combustor Outlet Temp. (°F)	2683	2894
Combustor Outlet Pres. (psia)	168.5	168.5
Turbine Subsystem Cooling Flow (pps)		
Water	142	173
Air	12	12
Turbine Exhaust Flow (pps)	697	716
Turbine Exhaust Temp. (°F)	1354	1475
Turbine Exhaust Pres.(psia)	14.9	14.9
Net Gas Turbine Shaft Output (MW)	163	187

directed toward finalizing the stage 1 nozzle design and the layout of the entire flow path. Mechanical design of the stage 1 nozzle will be initiated. The fuel to be used for simulating the low-Btu gas during the Phase 2 testing will be selected.

REPORTING CATEGORY VI

TASK 6 - DEVELOP PRELIMINARY PHASE 3 TEST PROGRAM PLAN

Work on this task is not scheduled to start until later in Phase 1.

REPORTING CATEGORY VII

TASK 7 - PERFORM PRELIMINARY DESIGNS OF THREE LOW-BTU GAS COMBUSTORS

WORK ACCOMPLISHED

Program planning and implementation activities are nearing completion for Task 7. Internal engineering documents are being established for defining combustion activities throughout the program as well as in Tasks 7 and 8.

The product low-Btu coal gas composition for design purposes was chosen to be that shown in Table 3. This gas was derived from the Illinois No. 6 coal. The gasification reaction was that of the GEGAS fixed-bed gasifier with a steam:air ratio of 0.198 and nominal gasifier pressure of 351 psia. Solid fuel emissions specifications of 1.2 lb. SO_2 per MMBTU of coal input and 0.7 lb NO_x per MMBTU of coal input were used to determine the gas cleanup system. The gas shown in Table 3 will be used throughout Phase 1 for Task 7 as well as Task 3 even though the product gas resulting from the Task 1 work may vary. It is not anticipated that the variations in product gas would significantly effect either the combustor or turbine subsystem designs.

The adiabatic flame temperature for the selected low Btu coal gas was calculated to be 3340°F. The NASA equilibrium computer program was used for these calculations. The combustor exit gas composition and specific heat were also calculated and are being tablulated.

WORK FORECAST

Combustor aerothermo design, cooling schemes, and heat transfer calculations will be initiated.

REPORTING CATEGORY VIII

TASK 8 - PREPARE TECHNOLOGY DEVELOPMENT PLAN FOR ONE COMBUSTOR

The combustor development plan will not begin until later in Phase 1.

TABLE 3

LOW-BTU COAL GAS COMPOSITION FOR DESIGN TASKS 3 AND 7

Constituent	Clean Product Gas (lb/lb. coal)
CO_2	.2725
CO	.8363
H_2S	.0030
COS	.0040
C_2H_4	.0086
C_2H_6	.0130
CH_4	.0847
H_2	.0341
N_2	1.4131
NH_3	.0014
Naptha	.0600
Tar	.0000
Phenol	.0065
TOTAL DRY GAS	2.7372
H_20	.7702
TOTAL NET GAS	3.5074

REPORTING CATEGORY IX

TASK 9 - MANAGEMENT

WORK ACCOMPLISHED

Discussions with subcontractors and General Electric organizations external to the Gas Turbine Division resulted in the generation of subcontracts, Work Statements and Terms and Conditions for cost plus fixed fee, labor-hour and firm fixed price contracts.

The following have been forwarded to ERDA for approval: C.F. Braun & Co., General Electric Corporate Research and Development Center and General Electric Aircraft Engine Business Group. These are all basically cost plus fixed fee contracts. Negotiations and discussions on terms and conditions are continuing with the Foster Wheeler Energy Corp. Similarly discussions of work scope are in process with General Electric Medium Steam Turbine, General Electric Materials and Processes Lab and General Electric Projects Engineering Organization.

A Labor-Hour Subcontract is ready for submission to ERDA based on acquiring five (5) Heat Transfer Engineers from the Polytechnic Design Corp. and the Belcan Corp.

A firm fixed price contract will be negotiated for the design of a Hot Gas Path Development Test Stand. Several responses have been received and are under review.

A top-level document representing the Program Plan was completely revised and updated to conform with the contract requirements. This was issued as DDM 443 Part I.

Part II of DDM 443 containing Project Administrative Instructions was similarly revised and is ready for issue.

Preliminary drafts of second-level documents have been reviewed and are in process of revision. These include Task Technical Plans, Schedules and Requirements which are issued by the responsible task leaders.

Preparation of Project Funding Authorization documents for labor expended within the Gas Turbine Division has begun. The Baseline Financial Plan was completed and forwarded to ERDA.

WORK FORECAST

During July the remaining subcontracts will be completed and forwarded to ERDA for approval. The Project Administrative Instructions will be issued early in July as Part II of DDM 443. Work will continue on the second-level documentation and the generation of the remaining PFA's.