1

f

o

1

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, 175 Oak Ridge Turnpike, Oak Ridge, TN 37831; prices available at (615) 576-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161; phone orders accepted at (703) 487-4650.

**CE IGCC Repowering Plant
Sulfuric Acid Plant**

**Topical Report
June 1993**

Arnold M. Chester

Work Performed Under Contract No.: DE-FC21-91MC26308

**For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
P.O. Box 880
Morgantown, West Virginia 26507-0880**

**By
Combustion Engineering, Inc.
1000 Prospect Hill Road
Windsor, Connecticut 06095-0500**

December 1993

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

SULFURIC ACID PLANT TOPICAL REPORT

TABLE OF CONTENTS

	Page
List of Tables	iii
I. Summary	1
II. Introduction	2
III. Background	3
A. Conventional Treatment Options	4
B. Hot Gas Clean Up System	6
C. HGCU Treatment Options	7
IV. Comparison Study	8
A. Basis	9
B. Results	11
C. Marketability of Sulfur	17
D. Recommendation	18
V. Sulfuric Acid Plant	19
A. Proposal	20
VI. Conclusions	22
VII. References	23
VIII. Figures	24
IX. Appendices (PROPRIETARY)	
A. Feasibility Study	
B. Tables	
C. Vendor Flow Diagrams and Sketches	
D. Flow Diagrams of Preferred System	
E. Monsanto Enviro-Chem Process Description and Flow Diagrams	
F. Monsanto Enviro-Chem Equipment List	

SULFURIC ACID PLANT TOPICAL REPORT

LIST OF TABLES

<u>No.</u>	<u>Title</u>	<u>Page</u>
1.	Cost Comparison Basis and Assumptions	10
2.	Integrated Conventional/HGCU Cost Comparison	12
3.	Integrated Conventional/HGCU Comparison Summary	13
4.	Stand-Alone HGCU Cost Comparison	15
5.	Stand-Alone HGCU Comparison Summary	16

I. SUMMARY

A goal of the CE IGCC Repowering project is to demonstrate a hot gas clean-up system (HGCU), for the removal of sulfur from the product gas stream exiting the gasifier island. Combustion Engineering, Inc. (ABB CE) intends to use a HGCU developed by General Electric Environmental Services (GEESI). The original design of this system called for the installation of the HGCU, with a conventional cold gas clean-up system included as a full-load operational back-up. Each of these systems removes sulfur compounds and introduces them into an acid gas, or off-gas. This report deals with the investigation of equipment to treat this off-gas, recovering these sulfur compounds as elemental sulfur, sulfuric acid or some other form.

ABB CE contracted ABB Lummus Crest Inc. (ABB LCI) to perform an engineering evaluation to compare several such process options. This study concluded that the installation of a sulfuric acid plant represented the best option from both a technical and economic point of view.

Based on this evaluation, ABB CE specified that a sulfuric acid plant be installed to remove sulfur from off-gas exiting the gas clean-up system. ABB LCI prepared a request for quotation (RFQ) for the construction of a sulfuric acid production plant. Monsanto Enviro-Chem Inc. presented the only proposal, and was eventually selected as the EPC contractor for this system.

II. INTRODUCTION

ABB CE is participating in a \$270 million coal gasification combined cycle repowering project that will provide a nominal 60 MWe of electricity to City Water, Light & Power (CWL&P) in Springfield, Illinois. The ABB CE project will demonstrate Integrated Gasification Combined Cycle (IGCC) technology in a commercial application by repowering an existing CWL&P plant. The project duration will be 126 months, including a 63 month demonstration period.

The IGCC system will consist of ABB CE's air-blown, entrained-flow, two-stage, pressurized coal gasifier; an advanced hot gas cleanup process; a combustion turbine adapted to use low-Btu coal gas; and all necessary coal handling equipment. CWL&P's Lakeside station will be the site for this project. The result of repowering will be an IGCC power plant with low environmental emissions and high net plant efficiency. The repowering will increase plant output by 40 MWe through addition of the combustion turbine, thus providing a total IGCC capacity of a nominal 60 MWe. Nearly half of the project will be funded by the United States Department of Energy (DOE), under round II of the Clean Coal Technology Program, while CWL&P, State of Illinois, and ABB CE will fund the rest.

The IGCC will include ABB CE's slagging, entrained-flow gasifier operating in a pressurized mode and using air as the oxidant. The hot gas will be cleaned of particulate matter (char) which is recycled back to the gasifier. After particulate removal, the product gas will be cleaned of sulfur prior to burning in a gas turbine.

The proposed project includes design and demonstration of an advanced hot gas cleanup process for removal of sulfur from the product gas. The sulfur removal method features a newly developed moving bed zinc titanate system downstream of the gasifier. ABB CE intends to use the General Electric (GE) moving bed, zinc titanate sulfur removal system currently being piloted by GE Environmental Systems, Inc.

In this plant, the gasifier will be producing a low-Btu gas (LBG). The LBG will be used as fuel in a standard GE gas turbine to produce power. This gas turbine will have the capacity to fire LBG and natural gas. Since firing LBG uses less air than natural gas, the gas turbine air compressor will have extra capacity. This extra compressed air will be used to pressurize the gasifier and supply the air needed in the gasification process.

The plant consists of three major blocks of equipment. They are the fuel gas island, which includes the gasifier and gas cleanup; gas turbine power block; and the steam turbine block, which includes the steam turbine and the heat recovery steam generator.

III. BACKGROUND

A goal of the CE IGCC Repowering Project is to demonstrate the removal and recovery of sulfur and other impurities in the product gas to environmentally acceptable levels consistent with the clean air standards mandated by the State of Illinois and the United States Environmental Protection Authority.

The preliminary plant arrangement on the IGCC Repowering Project included dual trains for the removal of sulfur gases. The hot gas clean up system (HGCU) selected by ABB CE is under development by General Electric Environmental Systems (GEESI). A conventional low temperature system was originally included in the project workscope. A range of low temperature systems were reviewed, considering plant integration, performance, capital and operating costs.

The syngas entering the parallel sulfur recovery systems is required at different conditions. Therefore, a complex equipment arrangement and flexibility is required should the gasifier block be able to operate alternately on both systems. In addition, there are several choices of conventional low-temperature sulfur removal system designs applicable to this project.

Whichever sulfur removal method is used, some means are needed to dispose of the resultant sulfur. The original plan of the project was to produce elemental sulfur. This form of sulfur has the potential for being a saleable byproduct. Its primary benefit, however, is that it represents the lowest mass byproduct stream. Alternate plans included producing sulfuric acid, or using limestone injection to capture the sulfur, disposing of the byproduct similarly to the waste from a scrubber. It was even considered that the existing Dallman station scrubber could be used to dispose of the acid gas.

To determine the most feasible sulfur recovery design for the project, ABB CE subcontracted ABB Lummus Crest Inc. (ABB LCI) to review the range of possible options and provide the "best" recommendation for the project. This report summarizes the technological and economic assessment efforts of ABB LCI, and documents the current sulfur recovery configuration for the Springfield project.

A. CONVENTIONAL TREATMENT OPTIONS

A number of possible configurations exist for the treatment of product gas in a conventional cold gas clean-up system. In each of these cases, raw product gas from the char removal baghouse is cooled and scrubbed to remove particulate matter. The gas is then passed through a bed of catalyst, which converts carbonaceous sulfide species to H_2S compounds by hydrolysis. Figures 1 through 6 illustrate the sulfur removal configurations utilizing cold gas clean-up. These configurations represent the most plausible range of sulfur removal and recovery options.

In configuration 1, sulfur is recovered as sulfuric acid. Gas leaving the hydrolysis unit is passed through an acid gas absorber where H_2S , CO_2 and trace quantities of ammonia, HCN, and particulates are absorbed by a circulating MDEA (methyldiethanolamine) stream. Clean product gas exits the top of this absorber and is reheated prior to combustion in the gas turbine. The MDEA stream exits the bottom of the absorber and enters a stripper. The cleaned MDEA re-enters the absorber while a stream of acid gas,

primarily H_2S , CO_2 , and water enters a sulfuric acid plant downstream of the stripper vessel. The sulfuric acid production process is addressed in a later section.

Configurations 2 and 3 replace the MDEA system / sulfuric acid plant combination with direct conversion processes for the production of elemental sulfur. Respectively, these are the Stretford or Lo-Cat processes. They are similar processes with similar installed costs. In each case, cooled raw gas undergoes selective hydrolysis and is scrubbed with a proprietary alkaline solution containing an oxidizing agent which converts H_2S to elemental sulfur and water. This sulfur is separated from the solution, concentrated and washed several times. The remaining solution is regenerated by oxidization with air, and recirculated to the absorber. The washed sulfur mixture is then heated under pressure to a temperature above the melting point of sulfur (245-275 F). At this point, the mixture is separated into two phases. The denser one, consisting essentially of pure sulfur, is sent to storage. The upper aqueous phase is either recycled or discharged. Flow diagrams for both of these systems, along with information related to their respective catalysts are included in the proprietary ABB LCI study (Appendix A).

Configuration 4 is similar to 2 and 3, but utilizes non-selective hydrolysis, rather than selective hydrolysis. This involves the use of a less-expensive catalyst. For the proposed operating environment, however, this substance would cause much of the CO present to be converted to CO_2 and hydrogen. This would significantly reduce the heating value of the product gas. For this reason, this configuration is not considered a reasonable option.

Configuration 5 uses chemical hydrolysis in lieu of catalytic hydrolysis, followed by Lo-Cat direct sulfur conversion. In this process, COS is hydrolyzed to H_2S using a diethanolamine (DEA) wash process. The DEA process hydrolyzes carbonaceous sulfide species to H_2S in a single step. However, the resulting acid gas is not sufficiently concentrated for conversion to elemental sulfur or sulfuric acid. It must then be passed through a Lo-Cat system. This additional equipment results in high installed costs, as

well as high steam requirements.

Configuration 6 represents a conventional system utilized in previous IGCC projects. It consists of selective hydrolysis, MDEA acid gas removal, Claus sulfur recovery, and Scot tail gas clean-up. This design can be viewed as the basis for the comparison of cost and performance of other systems. This configuration in itself is not viable for the Springfield project, because of its low turn-down capability and extensive purge requirement during start-up. In addition, a system utilizing a Claus plant is not recommended because of the HGCU system off-gas requirements.

B. HOT GAS CLEAN-UP SYSTEM

As noted previously, the cold gas clean-up configuration is specified to serve as a back-up to the GEESI HGCU system. For this reason, determination of the optimum treatment system for the acid gas produced by the HGCU is the major concern of this investigation. Figure 7 illustrates the GEESI HGCU process.

The HGCU receives syngas leaving the Char Removal Baghouse, which has been cleaned of particulate matter. This product is expected to consist primarily of N_2 , CO, H_2 and water, with low concentrations of H_2S , COS, CS_2 and HCl. The sulfur and chlorine compounds must be removed from the gas prior to combustion in the gas turbine.

HCl is removed from the gas upstream of the absorber. Nahcolite is injected into the syngas after the char removal baghouse. The Nahcolite converts the chlorine into NaCl which is a solid and can be filtered out and disposed of off site. Solids are separated in a cyclone before the gas enters the absorber.

The syngas enters the absorber and flows countercurrent to a moving bed of zinc titanate pellets. The sulfur compounds (mainly H_2S , COS and CS_2) in the gas react with the sorbent. Following sulfur absorption, spent sorbent material is conveyed to a lockhopper

and then to regeneration.

In the regenerator, the zinc titanate sorbent is regenerated and SO_2 is produced. Regenerated sorbent, purged of SO_2 is recycled to the absorber bin. The supply of regenerated sorbent is slightly depleted during regeneration and handling. Fine particles entrained in the cleaned gas stream are captured in a downstream high efficiency cyclone. Because of generation and removal of these fines, the sorbent requires replenishment at an expected rate of less than 1% of the continuous sorbent flow. The zinc titanate fines, because of their high zinc content, are recycled to the sorbent supplier.

Heat released in the regeneration process is used to generate steam which is piped back to the gasifier steam drum. The clean syngas is piped to the gas turbine for combustion. The SO_2 -rich gas produced during sorbent regeneration represents the sulfur recovery influent stream.

C. HGCU TREATMENT OPTIONS

There are several process options for the treatment of this regeneration "off-gas", resulting in the conversion of gaseous sulfur compounds to either elemental sulfur or sulfuric acid. Figures 8 through 10 illustrate three configurations evaluated in this study.

Configuration A converts the SO_2 from the acid gas to sulfuric acid. The off-gas leaving the HGCU is cooled and sent to a sulfuric acid plant. Sulfur arriving as SO_2 is converted to commercial-grade sulfuric acid. This result is achieved via Monsanto Enviro-Chem's contact process plant. The details of this design are proprietary, but a generic example of a conventional sulfuric acid plant is included later in this report.

Configuration B converts the acid gas SO_2 to elemental sulfur via the Allied Chemical direct reduction process. The SO_2 -rich off-gas is reduced by the addition of heated

natural gas. This mixture is further heated, and part of the hot gas mixture is passed over a proprietary catalyst where sufficient H_2S is formed to react with the remaining SO_2 to form elemental sulfur. SO_2 reduction is initiated in the reduction reactor, and is carried to near completion in two stages of Claus catalytic reducers with interstage elemental sulfur removal.

Configuration C is a process under development by United Catalysts, and is not yet commercially proven. In this design, the entire SO_2 stream from the HGCU is hydrogenated to H_2S . This is accomplished by combining the off-gas with partially oxidized natural gas and passing the mixture through a single-stage hydrogenation reactor. The gas containing H_2S is then cooled and subsequently converted to sulfur in a direct conversion process, such as Stretford or Lo-Cat.

A fourth configuration was also investigated. This design called for routing the acid gas produced by the HGCU to the scrubber located at the existing Dallman station. This scrubber is working well and is oversized for its present operation. This appears to be an attractive option from both a technical and economic point of view. However, CWL&P has indicated that this option is not available due to restrictions contained in existing labor agreements at the two plants as well as air permit requirements.

IV. COMPARISON STUDY RESULTS

In mid-1991 ABB LCI performed an engineering evaluation to compare, technically and economically, the process options for treatment of coal gas using the configurations listed above. The study anticipated that during the demonstration of the gasifier, the normal operating mode would be the HGCU, with the conventional unit considered a full load operational back up system.

A. BASIS

Options considered in the study included:

- Conventional schemes consisting of wet scrubbing for particulate removal, hydrolysis and amine absorption of sulfur species, coupled with various processes to produce elemental sulfur.
- Systems for sulfuric acid production from both HGCU off-gas from sorbent regeneration and acid gas from conventional schemes.
- Systems for the production of elemental sulfur from HGCU off-gas.

The basis for the study was the following:

- 75,000 lbs/hr of coal feed, containing 3% sulfur
- Design for 95% removal of total sulfur in gas stream
- System to have the ability to operate over a wide range of operating conditions including near zero flow
- Accommodate plant load changes of 3% per minute
- Pressure drop should be minimized
- 1991 costs
- Budgetary vendor input
- Sulfur as a saleable product - price based on ABB LCI estimates and CEH Marketing Research Report

The gaseous constituents and conditions for the fuel gas inlet of the gas clean-up systems was defined by ABB CE. The HGCU regenerator off-gas composition and conditions were developed by GEESI.

The remaining basis for the analysis is included in Table 1.

TABLE 1: COST COMPARISON BASIS AND ASSUMPTIONS

PLANT COST	TOTAL INSTALLED COST FOR BATTERY LIMIT PLANT BASED ON PRELIMINARY VENDOR INFORMATION AND 1991 COSTS
PRODUCT	BASED ON VENDOR ESTIMATES
SULFUR RECOVERY	OVERALL RECOVERY BASED ON SALEABLE PRODUCT / TOTAL SULFUR IN RAW GAS
UTILITY AND CHEMICAL CATALYST	CONSUMPTIONS BASED ON VENDOR ESTIMATES. HYDROLYSIS MAKE-UP CATALYST BASED ON 50% REPLACEMENT PER ANNUM
UTILITY COSTS STEAM POWER WATER NATURAL GAS	\$2.50 / M LBS .06 / KWH .02 / MGAL (COOLING WATER) 2.00 / MM BTU
CHEMICAL COSTS	BASED ON VENDOR SUPPLIED ESTIMATES
CATALYST COSTS	BASED ON VENDOR SUPPLIED ESTIMATES
LABOR SUPERVISION	3 MEN PER SHIFT 25% OF LABOR
DEPRECIATION MAINTENANCE TAXES AND INSURANCE	20 YEARS STRAIGHT LINE 5% OF TIC 4% OF TIC
MARKET VALUE OF PRODUCT	SULFURIC ACID \$70 / TON SULFUR \$105 / TON PLANT OPERATES 6750 HRS / YR
NET RECOVERY COST	TOTAL COST - VALUE OF PRODUCT

B. RESULTS

For the conditions listed, the integrated hot/cold clean-up system with sulfuric acid manufacture represented both the lowest predicted cost and the best expected performance. The process would produce 98.5% (weight) sulfuric acid. Total installed cost would be \$15 million with an operating cost of \$2.5 million / year operating in the HGCU mode. This process represents the highest sulfur recovery, smallest waste stream production, and adequate response to constituents change and turndown.

The integrated system utilizing the Stretford direct sulfur recovery process in the place of the sulfuric acid plant is expected to react better to load change and turndown. However, the TIC is expected to be \$22 million, with operating costs exceeding \$5 million / year when in the HGCU mode. The resultant sulfur is of low quality, containing high moisture content. In addition, the overall sulfur recovery is less than that predicted for the sulfuric acid plant configuration.

Replacing the Stretford system with a Lo-Cat direct sulfur recovery process for treating the HGCU system off-gas and adding an MDEA / Claus configuration for the conventional system would reduce costs somewhat. Estimated TIC is \$20.1 million, with an annual operating cost of \$3.3 million when operating the hot clean-up unit solely. However, the Lo-Cat process also produces a low quality, high moisture content elemental sulfur. Like the Stretford process, this configuration represents a diminished overall sulfur recovery as compared to the configuration utilizing the sulfuric acid plant configuration.

Tables 2 and 3 summarize the results of the integrated conventional / HGCU system study. Specific performance predictions and process data related to these configurations are considered proprietary and are included in proprietary Appendices A thru D.

TABLE 2
INTEGRATED CONVENTIONAL / HGCU SYSTEM
INSTALLED AND OPERATING COST COMPARISON
Basis: 100% HGCU Operation, 100% Conventional Operation

PRODUCT	SULFURIC ACID	ELEMENTAL SULFUR	ELEMENTAL SULFUR	ELEMENTAL SULFUR
CONVENTIONAL CONFIGURATION	SELECTIVE HYDROLYSIS, MDEA AGR SULFURIC ACID	SELECTIVE HYDROLYSIS SULFUR VIA STRETFORD / LO-CAT	SELECTIVE HYDROLYSIS, MDEA AGR CLAUS SULFUR RECOVERY	SELECTIVE HYDROLYSIS SULFUR VIA STRETFORD / LO-CAT
HGCU OFF-GAS CONFIGURATION	DIRECT CONVERSION TO SULFURIC ACID	CATALYTIC HYDROGENATION TO H ₂ S. CONVERSION TO ELEMENTAL SULFUR VIA STRETFORD / LO-CAT	ALLIED SIGNAL DIRECT REDUCTION TO SULFUR	TREATMENT OF HGCU OFF-GAS IN EXISTING FGDU
TIC	\$15,000,000	\$22,000,000	\$20,180,000	\$17,500,000
OPERATING COST CONVENTIONAL MODE	\$3,415,700 / YR.	\$5,561,500 / YR.	\$4,141,280 / YR.	\$4,931,500 / YR. (3)
OPERATING COST HGCU MODE	\$2,522,200 / YR.	\$5,192,800 / YR.	\$3,337,760 / YR.	NOT DETERMINED (3)

Notes: 1) Total installed costs presented here are for comparative evaluation only and are based on some vendor input and in-house data.

2) See Table 1 for cost comparison basis and assumptions.

3) These operating costs, which include maintenance and depreciation costs, all based on the installed cost of the total facilities in the row above.

TABLE 3
INTEGRATED CONVENTIONAL / HGCU SYSTEM
(75,000 LBS/HR COAL FIRING)

OPTION	SULFUR PRODUCT	TIC \$MM	PROCESS OPERATING COST \$/YR.	PART LOAD OPERATION OF BOTH SUMULTANEOUSLY	SULFUR RECOVERY	WASTE STREAM PRODUCTION (2)	LOAD CHANGE HANDLING	TURNDOWN CAPABILITY	REMARKS
SULFURIC ACID PRODUCTION	98.5 WT. % H_2SO_4	15.00	SEE TABLE 3	VERY GOOD	VERY HIGH	VERY SMALL	GOOD	GOOD	MAY NEED HCN WASH
STRETFORD CONVERSION	LOW QUALITY SULFUR	22.00	SEE APPENDIX B	GOOD (1)	ACCEPTABLE	HIGH	VERY GOOD	VERY GOOD	MAY NEED HCN WASH. MORE EXPERIENCE W/ COAL GAS
LO - CAT CONVERSION	LOW QUALITY SULFUR	20.18	SEE APPEDIX B	GOOD (1)	ACCEPTABLE	HIGH	VERY GOOD	VEY GOOD	MAY NEED HCN WASH
CLAUS / SCOT	HIGH QUALITY SULFUR	17.5	SEE APPENDIX B	GOOD	HIGH	VERY SMALL	VERY POOR	VERY POOR	MAY NEED HCN WASH

Notes: 1) Will require a compressor to boost the pressure of the HGCU off-gas to 300 psia.

2) Chemical waste, such as byproduct of a reactor, which may need continuous purging.

The study also included an evaluation of off gas treatment options when only the HGCU is installed. Configurations A through C (Figures 8-10) were compared, along with flue gas scrubbing. In this analysis, the estimated installed costs do not include the cost of the HGCU unit itself.

Again, the sulfuric acid plant was judged to be the best sulfur removal choice from both a performance and economic standpoint. TIC for the acid plant was estimated at \$5.5 million, with an annual operating cost of \$942,000 / year. The resultant sulfuric acid was valued at \$1.55 million, indicating a \$612,000 annual profit resulting from the sale of the product. Sulfur recovery was estimated at 97%. The plant would produce a small amount of waste, and would respond well to turndown and load change.

Configuration B, utilizing the Allied Chemical Direct Reduction process has a \$10.1 million TIC, with a net operating cost of \$979,000 per year. Sulfur recovery with this process is predicted to be 94%. This process would also respond well to both turndown and load change. It is the least-proven of the options studied.

Configuration C, utilizing the Lo-Cat direct sulfur recovery process has a TIC of \$8.85 million, and a net annual operating cost of \$3.4 million. Predicted sulfur recovery is 92%, and load change and turndown capabilities are adequate.

Configuration D consisted of flue gas scrubbing. This method, currently employed on "conventional" pulverized coal boilers, involves the injection of limestone, and ultimately produces gypsum. Sulfur recovery with this option was estimated at 90%. TIC would be \$15 million, with a net annual operating cost of \$4.25 million. This operating cost figure assumes that the resultant gypsum can be sold. In some industrial power applications, this is not the case, and operating costs could be even higher.

Tables 4 and 5 summarize the results of the study addressing a stand alone HGCU system.

TABLE 4
STAND ALONE HGCU UNIT
INSTALLED AND OPERATING COST COMPARISON (notes 1 and 2)

CONFIGURATION	A	B	C	D
PROCESS	DIRECT PRODUCTION OF SULFURIC ACID	ELEMENTAL SULFUR BY ALLIED CHEMICAL DIRECT REDUCTION PROCESS	HYDROGENATIONN OF SO ₂ - CONVERSION TO ELEMENTAL SULFUR BY LO-CAT	FLUE GAS SCRUBBING OF VENT STREAM
PLANT COST (TIC) PRODUCT SULFUR RECOVERY	\$5,500,000 81.3 TPD SULFURIC ACID 97%	\$10,130,000 26.5 TPD SULFUR 94%	\$8,850,000 24.2 TPD SULFUR 92%	\$15,000,000 GYPSUM 90%
UTILITIES REQUIRED STEAM POWER WATER NATURAL GAS	- 103 KW 300 GPM -	(-4400) LB/HR 30 KW - 375 SCFM	(-6500) 95 KW - 2550 SCFM	
CHEMICALS CATALYSTS	-	-	306 FT ³	
COST OF UTILITIES STEAM POWER WATER NATURAL GAS	- 40,600 2,400 -	(-72,270) 11,830 - 254,000	(-110,000) 33,500 1,900,000 -	
ANNUAL CHEMICAL COSTS CATALYST COSTS	- 4,000	- 3,000	814,000 40,000	2,000,000
ANNUAL LABOR SUPERVISION	100,000 25,000	100,000 25,000	100,000 25,000	100,000 25,000
ANNUAL DEPRECIATION MAINTENANCE TAXES AND INSURANCE	275,000 275,000 220,000	506,000 506,000 405,000	442,500 442,500 354,000	750,000 750,000 600,000
ANNUAL TOTAL COST	\$942,000	\$1,738,560	\$4,045,500	\$4,225,000
VALUE OF PRODUCT	\$1,554,000 / YEAR	\$759,620 / YEAR	\$693,700 / YEAR	-
NET RECOVERY COST	(-\$612,000) / YEAR	\$978,940 / YEAR	\$3,351,800 / YEAR	\$4,225,000 / YEAR

Notes: 1) Total installed costs presented here are for comparative evaluation only and are based on some vendor input and in-house data.
2) See Table 1 for cost comparison basis and assumptions.

TABLE 5
(75,000 LBS/HR COAL FIRING)
STAND ALONE HGCU UNIT

OPTION DEFINITION	SULFUR RECOVER- ED AS	TIC \$ MM	OPERATING COST \$ MM/YR	SULFUR RECOVERY	PROCESS WASTE STREAM	LOAD CHANGE HANDLING	TURN- DOWN	FACILITY FOR FUTURE HGCU INSTAL- LATION
HGCU OFF GAS > H ₂ SO ₄	SULFURIC ACID	5.5	-0.612	HIGH	SMALL	GOOD	GOOD	GOOD (1)
HGCU OFF GAS > ALLIED SIGNAL UNIT	ELEMENTAL SULFUR	10.13	0.979	ACCEPT- ABLE	VERY HIGH	GOOD	GOOD	GOOD (1)
HGCU OFF GAS > HYDROGENATION > LO-CAT	MOLTEN SULFUR	8.85	3.351	ACCEPT- ABLE	SMALL	GOOD	GOOD	GOOD
HGCU OFF GAS > MIX WITH AIR > FGD	GYPSUM	15.00	4.225	90%	HIGH	GOOD	GOOD	GOOD

Notes: 1) Will require a small compressor

At the conclusion of the study, a concern remained regarding the storage and removal of the product sulfuric acid. The cost comparisons for the production of sulfuric acid versus elemental sulfur did not include the cost of storage and / or transportation of the product. As for storage, it was determined, qualitatively, that lined tanks for storage and trailers for the transportation of commercial-grade sulfuric acid would not represent a significant cost increase.

C. MARKETABILITY OF SULFUR

In the comparison of these configurations, a major issue is whether sulfur or sulfuric acid will be a saleable byproduct, or a waste. In this situation, i.e. Springfield, Illinois, it is valid to expect that either elemental sulfur or sulfuric acid could be sold. This is due to the plant's close proximity to agricultural areas. As a result, several fertilizer manufacturing facilities are located nearby. The largest application of sulfur and sulfuric acid is in the production of fertilizers.

In most cases, fertilizer plants receive elemental sulfur, and convert it to sulfuric acid on site for their manufacturing process. This is not done because elemental sulfur is preferred, but because the local supply consists primarily of elemental sulfur, not sulfuric acid. If acid were locally produced, it could be utilized directly by these plants, eliminating their need for acid production.

For an application located near such a potential sulfur market, it is reasonable to assume that sulfur would be a commodity of some economic value. For plants in other regions, however, this market does not exist, and sulfur or sulfuric acid would become a product which must be disposed of, at some cost. As for the Springfield project, market research by ABB LCI has indicated that an agreement could be reached with a nearby fertilizer plant to take all sulfur or sulfuric acid produced by the plant. Such a contract would assure that the plant's storage capabilities would never be exceeded. User arrangements of this sort are to be defined during Budget Period Three.

D. RECOMMENDATION

Results of the study lead to the recommendation that for the project as defined in mid-1991 a plant to manufacture sulfuric acid be installed. That is, those configurations illustrated by Figures 1 and 8 be installed to treat the conventional and HGCU gas streams, respectively. This recommendation is based on the following:

Results indicated that both the installed and operating costs of the sulfuric acid plant are significantly less than those of Allied Chemical, Stretford or Lo-Cat processes. In addition, the sulfuric acid produced by this plant would represent about twice the potential revenue than would the elemental sulfur produced by the other methods. This decreases the comparative operating cost of the sulfuric acid system, making it more economically attractive.

The acid plant can handle a wide range of loads, accommodating turn-down ratios as low as 15%, thus maintaining consistent plant emissions during low-load operation. Other systems with this flexibility offer lower total sulfur recovery, a lower quality product and higher installed and operating costs.

This option represents the highest sulfur recovery rate, 97% and above.

A sulfuric acid plant is the most amenable system to accommodate flow rate and gas constituent variations.

This process represents the least amount of required integration with the HGCU.

The process represents the lowest technical risk. The contact process for production of sulfuric acid has been used commercially for decades. Monsanto Enviro-Chem Systems, Inc. alone has installed over 700 plants world wide.

The study also concluded that for a plant design with a stand alone HGCU system for sulfur removal the sulfuric acid system represented the most feasible recovery system.

The Springfield project progressed in 1992 into a basic or preliminary engineering phase. The cost estimate produced based upon the preliminary engineering exceeded the project funding level. As a result, a cost reduction effort was initiated which resulted in the exclusion of the conventional sulfur removal equipment from the project workscope. However, the conclusions reached in the ABB LCI feasibility study of sulfur removal systems remain valid, i.e. with a stand alone HGCU system a sulfuric acid plant (Figure 7) is the best recovery option.

V. SULFURIC ACID PLANT

The sulfuric acid production process evaluated in the ABB LCI report was the contact process of Monsanto Enviro-Chem Systems, Inc., of St. Louis, Missouri. The design is well-proven in commercial applications, with over 700 plants constructed to date. A confidentiality agreement precludes the inclusion of technical and commercial information related to the Springfield project in this report. A process description and flow diagrams are included in proprietary Appendix E. However, a general explanation of this process is published publicly, and an excerpt is included below. (2)

Off-gas containing SO_2 is pulled through a scrubbing tower where it is cleaned and cooled to its adiabatic saturation temperature by recirculating weak acid. Next, the gas is cooled in the gas cooling tower, to a point where the moisture level is reduced to the amount required in the product acid. The final stage of gas cleaning is the electrostatic precipitator which removes both liquid and solid particulate matter which would otherwise cause corrosion and fouling in the acid plant. The gas is then pulled through the high-efficiency drying tower where the remaining water vapor is removed. A mist eliminator provides acid mist removal for the protection of the main compressor. The dry, clean gas is then compressed and introduced to the converter system.

In the catalytic converter, SO₂ is oxidized to SO₃ according to the equation:

Because the reaction is highly exothermic and reversible to obtain the high degree of conversion required to meet current environmental plant emissions standards, the conversion reaction is carried out in stages (passes) with heat removal between passes. To achieve the final increment of required conversion in current sulfuric acid plants, SO₃ must be removed from the process gas stream prior to passing through the final conversion pass(es).

Monsanto Enviro-Chem has standardized its system of interpass absorption of SO₃ from the converter process gas after it has passed through the initial three passes in the converter because this configuration gives the best conversion under both normal and upset conditions.

After passing through the first three layers of catalyst, SO₃ rich gas is cooled and absorbed with 98% sulfuric acid (H₂SO₄) in the interpass absorption tower. The lean SO₂ gas flows through a mist eliminator to remove fine mist particles, thereby protecting downstream equipment. The clean gas is then reheated and enters the converter to complete the conversion of SO₂ to SO₃. The SO₃ is absorbed in 98% H₂SO₄ in the final tower. Mist eliminators are installed in the final tower to insure the stack gas will meet environmental regulations on acid mist.

Figure 11 illustrates this process.

A. PROPOSAL

As a result of the basic engineering phase work and the ABB LCI feasibility study, a sulfuric acid plant is included in the Springfield project plant design. To facilitate the

latest plant workscope price estimate, a request for proposal (RFP) document was let in October 1992 for a turnkey lump-sum quotation for engineering, procurement and construction (EPC) of a sulfuric acid plant. The current plant design for the City of Springfield includes a sulfuric acid plant designed and supplied by Monsanto Enviro-Chem, based upon the quotation received in December 1992.

The plant cost estimate presents an inconsistency with the ABB LCI study. The estimated total installed cost (TIC) for the turnkey sulfuric acid plant is approximately twice that of the ABB LCI estimate. This suggests further investigation is required to completely understand the process involved. However, even at this higher price, the TIC for an acid plant is roughly equal to those of the alternate configurations. In addition, the operating cost and predicted performance still indicates that the installation of a sulfuric acid plant is the best technology for this application.

As stated earlier, a confidentiality agreement precludes the inclusion of technical and commercial information contained in the EPC bid in the public section of this report. Process information is contained in proprietary Appendix B.

VI CONCLUSIONS

Based on the ABB LCI study, a sulfuric plant represents the best means for disposing of sulfur removed from the product gas by the Hot Gas Clean-Up system. Although the estimated TIC for a turnkey plant in the study was inconsistent with Monsanto's proposal this technology still represents the lowest installed cost of the viable options.

Operating costs associated with this system are considerably lower than the other options if sulfuric acid is a saleable product. A brief, preliminary investigation indicates that a market exists for sulfur and sulfuric acid near the project site. The details of reaching a supply agreement will be addressed in Budget Period Three.

Based on this conclusion, and performance predictions contained in the ABB LCI assessment, ABB CE selected a sulfuric acid plant as the sulfur removal system for use with the HGCU on the CE IGCC Repowering Project. ABB LCI prepared a request for proposal, and Monsanto Enviro-Chem was chosen as EPC contractor by ABB CE. Cost and process data furnished by Monsanto comprised the basis for the City of Springfield plant cost estimate.

VII REFERENCES

1. ABB Lummus Crest Inc., Feasibility Study Report: Sulfur Recovery Systems. Prepared for Combustion Engineering Inc., September, 1991.
2. Monsanto Enviro-Chem Systems, Inc., sulfuric acid plant brochure, 1984.
3. W.L. Faith, D.B. Keys and R.C. Clark, Industrial Chemicals. New York: John Wiley and Sons, Inc. 1950.
4. Monsanto Enviro-Chem Systems, Inc., Technical Specification 2698: Integrated Gasification Combined Cycle Plant, Revision. December 1992.
5. Barbara Heydorn, Diane Lopez and Don Lauriente of Chemical Economics Handbook, CEH Marketing Research Report: Sulfur. Chemical Economics Handbook - SRI International, 1987.

VIII FIGURES

1. Configuration 1
2. Configuration 2
3. Configuration 3
4. Configuration 4
5. Configuration 5
6. Configuration 6
7. GEESI Hot Gas Clean Up System
8. Configuration A
9. Configuration B
10. Configuration C
11. Sulfuric Acid Plant

CONFIGURATION 1
SELECTIVE HYDROLYSIS - SELECTIVE H₂S REMOVAL WITH MDEA
SULFUR RECOVERY IN CONTACT SULFURIC ACID PLANT

FIGURE 1

CONFIGURATION 2
SELECTIVE HYDROLYSIS - LO-CAT SULFUR CONVERSION

FIGURE 2

CONFIGURATION 3
SELECTIVE HYDROLYSIS - STRETTFORD SULFUR CONVERSION

FIGURE 3

CONFIGURATION 4
NON-SELECTIVE HYDROLYSIS - STRETTFORD SULFUR CONVERSION

FIGURE 4

CONFIGURATION 5
CHEMICAL HYDROLYSIS - LO-CAT DIRECT SULFUR RECOVERY

FIGURE 5

CONFIGURATION 6
SELECTIVE HYDROLYSIS - MDEA H₂S REMOVAL
CLAUS SULFUR RECOVERY - SCOT UNIT

FIGURE 6

Figure 7: Hot Gas Clean Up System

**CONFIGURATION A
GEESI HGCU WITH SULFURIC ACID PRODUCTION**

FIGURE 8

CONFIGURATION B
GEESI HGCU WITH ELEMENTAL ACID PRODUCTION
BY ALLIED CHEMICAL DIRECT REDUCTION PROCESS

FIGURE 9

CONFIGURATION C
GEESI HGCU WITH HIGH TEMPERATURE CATALYTIC HYDROGENATION OF
SULFUR DIOXIDE TO HYDROGEN SULFIDE AND SUBSEQUENT DIRECT SULFUR
RECOVERY (STRET福德 OR LO-CAT PROCESS)

FIGURE 10

FIGURE 11. SULFURIC ACID PLANT

**DATE
FILMED**

4 / 11 / 94

END