CONTRACTOR REPORT

SAND87-8177
UC-62c
Unlimited Release

Solar Fuels and Chemicals System Design Study - Production and Regeneration of Activated Carbon Final Report Volume 1 - Executive Summary

Babcock and Wilcox
A McDermott Company
Nuclear Equipment Division
Barberton, Ohio 44203

Prepared by Sandia National Laboratories, Albuquerque, New Mexico 87185 and Livermore, California 94550 for the United States Department of Energy under Contract 91-4648B.

Printed March 1987

Printed in the United States of America
Available from
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes
Printed copy: A03
Microfiche copy: A01

UC-62c

SAND87-8177
Unlimited Release
Printed March 1987

SOLAR FUELS AND CHEMICALS SYSTEM DESIGN STUDY - PRODUCTION AND REGENERATION OF ACTIVATED CARBON
FINAL REPORT
VOLUME 1 - EXECUTIVE SUMMARY

Babcock and Wilcox
A McDermott Company
Nuclear Equipment Division
Barberton, Ohio 44203

Prepared for Sandia National Laboratories
under Contract No. 91-4648B

ABSTRACT

This report describes the conceptual design of a solar thermal central receiver system that both produces activated carbon from coal and regenerates spent activated carbon. The system design uses molten carbonate salt that is heated in the receiver to transfer heat to an activated carbon plant located near the base of the receiver tower. Capital and operating cost estimates are described, and market and economic analyses are presented to assess the attractiveness of the proposed system. Technical uncertainties are identified as the basis for a development plan to bring the proposed system to maturity.

SOLAR THERMAL TECHNOLOGY
FOREWORD

The research and development described in this document was conducted within the U.S. Department of Energy's (DOE) Solar Thermal Technology Program. The goal of the Solar Thermal Technology Program is to advance the engineering and scientific understanding of solar thermal technology, and to establish the technology base from which private industry can develop solar thermal power production options for introduction into the competitive energy market.

Solar thermal technology concentrates solar radiation by means of tracking mirrors or lenses onto a receiver where the solar energy is absorbed as heat and converted into electricity or incorporated into products as process heat. The two primary solar thermal technologies, central receivers and distributed receivers, employ various point and line-focus optics to concentrate sunlight. Current central receiver systems use fields of heliostats (two-axis tracking mirrors) to focus the sun's radiant energy onto a single tower-mounted receiver. Parabolic dishes up to 17 meters in diameter track the sun in two axes and use mirrors or Fresnel lenses to focus radiant energy onto a receiver. Troughs and bowls are line-focus tracking reflectors that concentrate sunlight onto receiver tubes along their focal lines. Concentrating collector modules can be used alone or in a multi-module system. The concentrated radiant energy absorbed by the solar thermal receiver is transported to the conversion process by a circulating working fluid. Receiver temperatures range from 100°C in low-temperature troughs to over 1500°C in dish and central receiver systems.

The Solar Thermal Technology Program is directing efforts to advance and improve promising system concepts through the research and development of solar thermal materials, components, and subsystems, and the testing and performance evaluation of subsystems and systems. These efforts are carried out through the technical direction of DOE and its network of national laboratories who work with private industry. Together they have established a comprehensive, goal directed program to improve performance and provide technically proven options for eventual incorporation into the Nation's energy supply.

To be successful in contributing to an adequate national energy supply at reasonable cost, solar thermal energy must eventually be economically competitive with a variety of other energy sources. Component and system-level performance targets have been developed as quantitative program goals. The performance targets are used in planning research and development activities, measuring progress, assessing alternative technology options, and making optimal component developments. These targets will be pursued vigorously to insure a successful program.

The production of fuels and chemicals using solar thermal energy would broaden the Program's impact on fossil fuel displacement and establish the full potential of solar thermal technology. This report describes the conceptual design of a solar thermal central receiver plant that both produces activated carbon from coal and regenerates spent activated carbon. Technology development needs are described, and market and economic analyses are presented.

Information in this report should be considered preliminary since the work was carried only through the conceptual stage. A key factor in sizing many of the components is the corrosion rates for the materials selected. Corrosion data for some of the materials specified are limited and subject to interpretation.

TABLE OF CONTENTS

Page

Volume 1

Executive Summary. 1

Volume 2

1.0 Introduction 1-1
1.1 Objective of the Study. 1-1
1.2 Project Plan. 1-2
1.3 Project Organization. 1-7
1.3.1 Project Team. 1-7
1.3.2 Team Member Responsibilities. 1-9

2.0 System Description 2-1
2.1 An Overview 2-1
2.2 Chemical Process Subsystem. 2-11
2.2.1 Process Description/Process Chemistry 2-12
2.2.2 Products/By-Products/Raw Materials/Utilities. 2-39
2.2.3 Component Description 2-46
2.3 Solar Heat Transport Subsystem. 2-77
2.3.1 Subsystem Description 2-77
2.3.2 Receiver. 2-82
2.3.3 Thermal Energy Storage. 2-119
2.3.4 Steam Generator 2-125
2.3.5 Fossil Fired Salt Heater. 2-138
2.3.6 Salt Pumps and Interconnecting Piping 2-144
2.4 Tower and Collector Field Subsystem 2-146
2.4.1 Design Approach 2-146
2.4.2 Tower 2-160
2.4.3 Collector Field Design. 2-161
2.4.4 Subsystem Performance 2-164
2.5 Balance of Plant. 2-164
2.5.1 Coal Handling System. 2-164
2.5.2 Electrical Generation System. 2-167
2.5.3 Water Systems 2-169
2.5.4 Storage Systems 2-172

TABLE OF CONTENTS

		Page
2.6	Overall Plant Layout.	2-176
	2.6.1 Central Plant Arrangement	2-176
	2.6.2 Site Arrangement.	2-177
2.7	System Operation and Control Strategy	2-180
	2.7.1 Chemical Process Subsystem Operation and Control Strategy.	2-180
	2.7.2 Solar Heat Transport Subsystem Operation and Control Strategy.	2-198
	2.7.3 Plant Control System.	2-207
2.8	Overall System Performance.	2-209
	2.8.1 Overview.	2-209
	2.8.2 Design Point Performance.	2-209
	2.8.3 Annual Energy and Product Production Projection .	2-212
3.0 Economic Assessment.		3-1
3.1	Operating Costs	3-1
	3.1.1 Power Plant	3-1
	3.1.2 Chemical Plant.	3-4
3.2	Capital Costs	3-11
3.3	Market Forecast	3-13
	3.3.1 Product Description	3-16
	3.3.2 Historical Perspective.	3-20
	3.3.3 Long-Term Forecast.	3-24
	3.3.4 Market Share Potential.	3-27
3.4	Evaluation of Data.	3-30
	3.4.1 Financial Analysis.	3-30
	3.4.2 Comparison to Fossil Fueled Plant	3-36
3.5	Areas for Potential Cost Reductions	3-40
3.6	Conclusions	3-43
4.0 Technological Uncertainties.		4-1
4.1	Development Plan Overview	4-1
	4.1.1 Organization.	4-1
	4.1.2 Solar Plant Maturity.	4-2
	4.1.3 Chemical Plant Maturity	4-4

TABLE OF CONTENTS

Page

4.2 Development Plan. 4-5
4.2.1 Material Development. 4-7
4.2.2 Salt Properties Development 4-13
4.2.3 Component Development 4-14
4.2.4 Economic Considerations 4-25
4.2.5 Ceramic Development Plan. 4-28

5.0 Conclusions and Recommendations. 5-1
5.1 Conclusions 5-1
5.2 Recommendations 5-3

6.0 References 6-1

Volume 3

7.0 Appendices

A. Material Selection

B. Equipment Specifications

C. Design Requirements

D. Economic Assessment Supporting Data

E. Uses and Applications for Activated Carbon

LIST OF TABLES

Page

Volume 1

1 Annual Energy and Product Production Projection. 17

Volume 2

1-1 Project Responsibilities 1-9
2-1 Total Carbonate Salt Heat Load Requirements. 2-9
2-2 Material Balances - Production of Activated Carbon 2-16
2-3 Typical Yield of Carbonization Products. 2-20
2-4 Typical Composition of Tar 2-21
2-5 Typical Composition of Light Oil 2-22
2-6 Typical Composition of Carbonization Gas 2-22
2-7 Material Balance - Regeneration of Activated Carbon. 2-34
2-8 Waste Water Streams. 2-37
2-9 Ranges of Properties of Granular Activated Carbon. 2-40
2-10 Composition of Product Gas 2-40
2-11 Steam Users. 2-43
2-12 Heat Duty of Coolers 2-45
2-13 Water Users. 2-45
2-14 Direct Contact Furnace 2-48
2-15 Rotary Drum Furnace. 2-49
2-16 Fluid Bed Furnace. 2-50
2-17 Multiple Hearth Furnace. 2-51
2-18 Multiple Plate Furnace 2-53
2-19 Furnace Design - Summary 2-56
2-20 Equipment Specification - Chemical Reaction Furnaces 2-57
2-21 Equipment Specification - Carbonization Furnace. 2-58
2-22 Equipment Specification - Activation Furnace 2-59
2-23 Equipment Specification - Regeneration Furnace 2-60
2-24 Overall Furnace Heat Loss. 2-61
2-25 Equipment List - Pretreatment. 2-65
2-26 Equipment List - Carbonization, Activation,
Product Classification. 2-67

LIST OF TABLES

		Page
2-27	Equipment List - Off Gas Cooling and Compression	2-68
2-28	Equipment List - Tar Recovery/Ammonia Removal	2-69
2-29	Equipment List - H_2S Removal and Sulfur Recovery	2-70
2-30	Equipment List - Regeneration	2-71
2-31	Equipment List by Item	2-73
2-32	Solar Receiver Requirements	2-82
2-33	Allowable Stress Range for Inconel 617	2-98
2-34	Heat Exchanger Geometric Characteristics	2-133
2-35	Heat Exchanger Performance Characteristics	2-133
2-36	Salt Heater Design and Sizing Specifications	2-143
2-37	Heliostat Field and Receiver Interface Design Summary	2-147
2-38	Design Point Heat Exchanger Surface Flux Map	2-154
2-39	Summary of Peak Direct Incident Fluxes - Various Receiver Configurations	2-156
2-40	Design Point Heat Exchanger Surface Flux Map	2-158
2-41	Design Point Aperture Flux	2-160
2-42	Typical Clear Day, 24 Hour Operating Scenario	2-202
2-43	Molten Salt Power Balance Based on Receiver Design Point	2-210
2-44	Receiver Design Point, Power and Material Flow Summary	2-211
2-45	Molten Salt Power Balance Based on Fossil Fired Salt Heater Design Point	2-213
2-46	Fossil Fired Salt Heater Design Point, Power and Material Flow Summary	2-214
2-47	Annual Energy and Product Production Projection	2-217

LIST OF TABLES

		Page
3-1	Power Plant Annual Operation and Maintenance Expenses	3-2
3-2	Daily Power Plant Staffing	3-3
3-3	Chemical Plant Annual Operation and Maintenance Expenses	3-5
3-4	Cost Analysis of Coal for Activated Carbon Production	3-8
3-5	Cost Analysis of Coal Tar Pitch for Activated Carbon Production	3-9
3-6	Production of Activated Carbon-Operating Labor Breakdown	3-10
3-7	Regeneration of Spent Carbon-Operating Labor Breakdown	3-10
3-8	Plant Capital Cost Summary	3-11
3-8a	Power Generation System Costs	3-12
3-8b	Process Plant Systems/Equipment Costs	3-12
3-9	Virgin Activated Carbon Supply/Demand Summary: United States	3-15
3-10	Selected Grades, Description of Properties, and Prices of Activated Carbons	3-18
3-11	U.S. Demand for Virgin Activated Carbon: A Historical Perspective	3-22
3-12	U.S. Demand for Virgin Activated Carbon: Short-Term Forecast	3-23
3-13	U.S. Demand for Granular Activated Carbon (GAC): Long-Term Forecast	3-26
3-14	U.S. Supply/Demand for All Activated Carbon-1983	3-27
3-15	Estimated GAC Production Capacity and Market Share	3-28
3-16	U.S. GAC Capacity Utilization in Year 2000	3-29
3-17	Annual Plant Production and Revenue Projections	3-31
3-18	Economic Assumptions and Variables	3-32
3-19	Financial Evaluation Results - Solar Plant	3-36
3-20	Financial Evaluation Results - Fossil Fueled Plant	3-37
3-21	Central Receiver Component Costs and Goals for Process Heat	3-41
3-22	Description of Areas for Component Goals	3-42
4-1	Development Task Activities	4-23

LIST OF FIGURES

Page

Volume 1

1 Chemical Process/Solar Central Receiver Plant Layout 5

2 Production of Activated Carbon Block Diagram 7

3 Regeneration of Spent Carbon 8

4 Solar Heat Transport Subsystem Schematic 11

5 Steam Generator Schematic. 12

Volume 2

1-1 Project Organization 1-8

2-1 Initial Chemical Process/Steam Generator Carbonate Salt Flow Diagram. 2-3

2-2 Revised Chemical Process/Steam Generator Carbonate Salt Flow Diagram. 2-5

2-3 Initial Steam Generator Subsystem Temperatures 2-7

2-4 Final Chemical Process/Steam Generator Carbonate Salt Flow Diagram. 2-8

2-5 Chemical Process/Solar Central Receiver Conceptual Plant Layout 2-10

2-6 Production of Activated Carbon Block Diagram 2-15

2-7 Production of Activated Carbon - Pretreatment. 2-19

2-8 Production of Activated Carbon - Carbonization/Activation/ Product Classification 2-25

2-9 Production of Activated Carbon - Tar Recovery/Ammonia Removal 2-27

2-10 Production of Activated Carbon - Sulphur Removal and Recovery. 2-30

2-11 Regeneration of Spent Carbon 2-33

2-12 Chemical Process Steam Generation. 2-44

2-13 Proposed Hearth Detail 2-55

2-14 Chemical Process Salt Control. 2-63

2-15 Piping and Instrument Diagram - Molten Salt. 2-78

2-16 Piping and Instrument Diagram - Co-generation. 2-79

2-17 Solar Heat Transport Subsystem Schematic 2-80

2-18 Steam Generator Schematic. 2-81

2-19 Solar Receiver Configuration 2-84

LIST OF FIGURES

		Page
2-20	Simplified Receiver Flow Schematic	2-85
2-21	Receiver Panel Design-Parametric Evaluation.	2-92
2-22	Peak Allowable Absorbed Flux vs. Salt Temperature.	2-93
2-23	Peak Allowable Absorbed Flux vs. Receiver Surface.	2-94
2-24	Allowable Receiver Design Pressure vs. Tube Temperature. . . .	2-95
2-25	Allowable Receiver Design Pressure/Temperature Regions	2-96
2-26	Peak Allowable Incident Flux vs. Salt Temperature.	2-106
2-27	Peak Allowable Incident Flux vs. Receiver Surface.	2-107
2-28	Peak Incident Flux - Initial Receiver Configuration.	2-108
2-29	Peak Incident Flux - Final Receiver Configuration.	2-109
2-30	Arrangement of Solar Receiver, Section B-B	2-110
2-31	Arrangement of Solar Receiver, Sectional Side View Looking West	2-111
2-32	Receiver Door Configuration.	2-116
2-33	Flow Schematic of Thermal Energy Storage Subsystem	2-121
2-34	High Temperature Thermal Storage Tank.	2-123
2-35	Low Temperature Thermal Storage Tank	2-124
2-36	Steam Generator Schematic.	2-126
2-37	Intermediate Heat Exchanger.	2-128
2-38	Superheater.	2-129
2-39	Evaporator	2-130
2-40	Steam Drum	2-132
2-41	Cross-Section of Ribbed Tubing	2-135
2-42	Fossil Fired Salt Heater Furnace Arrangement	2-139
2-43	Fossil Fired Salt Heater Location Arrangement.	1-140

LIST OF FIGURES

		Page
2-44a	Analysis of Tower Height	2-150
2-44b	Aperture Size Analysis	2-151
2-45	Aperture Tilt Analysis	2-153
2-46	Ceiling Flux Map	2-159
2-47	Solar Receiver Support Tower	2-162
2-48	Collector Field and Tower Layout	2-163
2-49	Efficiency Stairsteps.	2-165
2-50	Central Plant Arrangement.	2-173
2-51	Site Arrangement	2-178
2-52	Process Control Diagram - Pretreatment	2-185
2-53	Process Control Diagram - Carbonization, Activation, and Off-Gas Cooling and Compression.	2-186
2-54	Process Control Diagram - Tar Recovery and Ammonia Removal.	2-187
2-55	Process Control Diagram - H_2S Removal and Sulphur Recovery	2-188
2-56	Process Control Diagram - Regeneration of Spent Carbon . . .	2-189
2-57	Process Control Diagram - Chemical Reaction Furnaces	2-190
2-58	Plant Control System Block Diagram	2-208
3-1	Internal Rate of Return (IRR) vs. Escalation Rate for Baseline Solar Plant	3-34
3-2	Internal Rate of Return vs. Capital Cost Reduction in Solar Portion of Plant.	3-35
3-3	Internal Rate of Return vs. Escalation Rate.	3-38
3-4	Relevant Costs and Revenues: Net Present Value vs. Escalation Rate.	3-39
4-1	Chemical Reaction Furnaces - Plan For Resolution	4-22
4-2	Corrosion Testing of Ceramic Materials	4-32

EXECUTIVE SUMMARY

1.0 INTRODUCTION

This report describes the results of a study headed by the Babcock & Wilcox Company, under contract with Sandia National Laboratories - Livermore (SNLL), to conceptually design and evaluate a facility for the production of activated carbon using energy supplied by a solar central receiver. The study was performed by a project team consisting of Babcock & Wilcox, the Chemicals Group of Olin Corporation, and Black & Veatch Engineers-Architects.

This work was envisioned as the first phase of a multi-phase program that could ultimately lead to the commercialization of the process. It supports the principal objective of Sandia's Solar Fuels and Chemicals Program of identifying and developing new applications for solar central receiver technology.

The specific objectives of this study were to uncover the design challenges and development requirements involved in defining a solar fuels and chemicals plant and to establish the technical and economic feasibility of the proposed concept. In support of this objective, the conceptual design and operating strategies were developed, upon which capital and operating cost estimates were based. A market forecast and a revenue projection were prepared. Technical uncertainties were identified as the basis for a development plan to bring the proposed concept to maturity.

A dual purpose process involving the production of activated carbon from coal and the regeneration of spent activated carbon was selected. The regeneration portion of the process will be partially fired by natural gas to reduce operating temperature demands on the receiver. In addition, the process will provide for the cogeneration of electrical power. This process was chosen after review of numerous processes, including coal gasification, steam reforming of methane to produce ammonia, and synthesis of ethylene from ethanol. The activated carbon process was selected because it is energy intensive, thereby offering considerable potential for the efficient and economic utilization of solar energy; it demands practical improvements in existing technology, advancing the state-of-the-art without high-risk development activity; and it is versatile, providing as by-products valuable syngas, tars and oils.

The project was managed by Babcock & Wilcox in accordance with a plan which organized the effort into several tasks.

In the Process Optimization task, the chemical process was refined and its important design characteristics established. The thermal demand to be supplied by the solar heat transport subsystem was established. A conceptual plant layout showing the arrangement and interface of the principal components in the process was prepared.

The Facility Design task included component/subsystem design, system design, and controls/operating strategy. Conceptual designs were developed for the major components in the solar heat transport subsystem, the chemical process subsystem, and the collector field subsystem. An integrated total system arrangement combining these three subsystems was developed, and a plant equipment layout was prepared. Operating strategies for various modes of plant operation were outlined, and control schemes for plant operation were defined. Design point and annual energy requirements as well as product outputs for the plant were projected.

The Technological Uncertainties task assessed the technical maturity of the plant, identified technical deficiencies or uncertainties, and devised plans for resolution of these weaknesses. A development plan documenting this task was prepared.

In the Cost and Economic Incentives task, capital cost estimates were prepared based on the plant equipment needs established by the facility design. Operating and maintenance costs were estimated on the basis of the costs of feedstock and other process consumables and of the cost of supervision and labor required to operate and maintain the plant. On the basis of a market forecast for activated carbon and other saleable by-products, revenue projections for the process were made. Combining these revenue projections with the capital and operating cost estimates, a financial evaluation of the process was completed.

2.0 SYSTEM DESCRIPTION

One of the major objectives of the Solar Fuels and Chemicals Design Study was to complete a conceptual design of a facility for the production of fuels and/or chemicals in which a significant portion of the consumed energy is supplied by a solar receiver. Completion of the system design supported the additional major objectives of the study of performing an economic evaluation of the process and of identifying the technological uncertainties of the design and the plans to resolve those uncertainties.

A dual-purpose chemical process involving the production of activated carbon from coal feedstock and the regeneration of spent activated carbon was selected on the basis of several factors. The process is energy intensive, thereby offering potential for efficient use of solar energy. The basic technology of the production and the regeneration processes has been developed, which provides a base for any technological changes to the processes required as a result of incorporating solar energy into the design. The process generates valuable by-product gas and tar which can be used as fuel for the process or as feedstock for other chemical processes, or can be sold to generate additional revenue. The plant also provides for generation of electrical power to meet process electrical requirements and to generate revenue.

The great majority of the energy input to the chemical process is provided by an intermediate heat transfer fluid, molten carbonate salt, to transport energy from the solar heat transport subsystem to the chemical process subsystem. The solar heat transport subsystem provides energy input to the carbonate salt on a 24 hour-a-day basis through the use of either a solar central receiver or a fossil fired salt heater. During periods of receiver operation, the thermal storage tanks decouple the operation of the chemical process from the receiver operation. This permits continual operation of the chemical process during cloud transients without the need to cycle the operation of the fossil fired salt heater. The steam generator portion of the solar heat transport subsystem uses energy input from the carbonate salt to generate steam both for the production of electrical energy and for the process requirements in the chemical process subsystem. The solar heat transport subsystem is a high temperature process in which broad design and materials technology developments can be applied to a variety of potential programs in addition to the specific chemical process considered in this study.

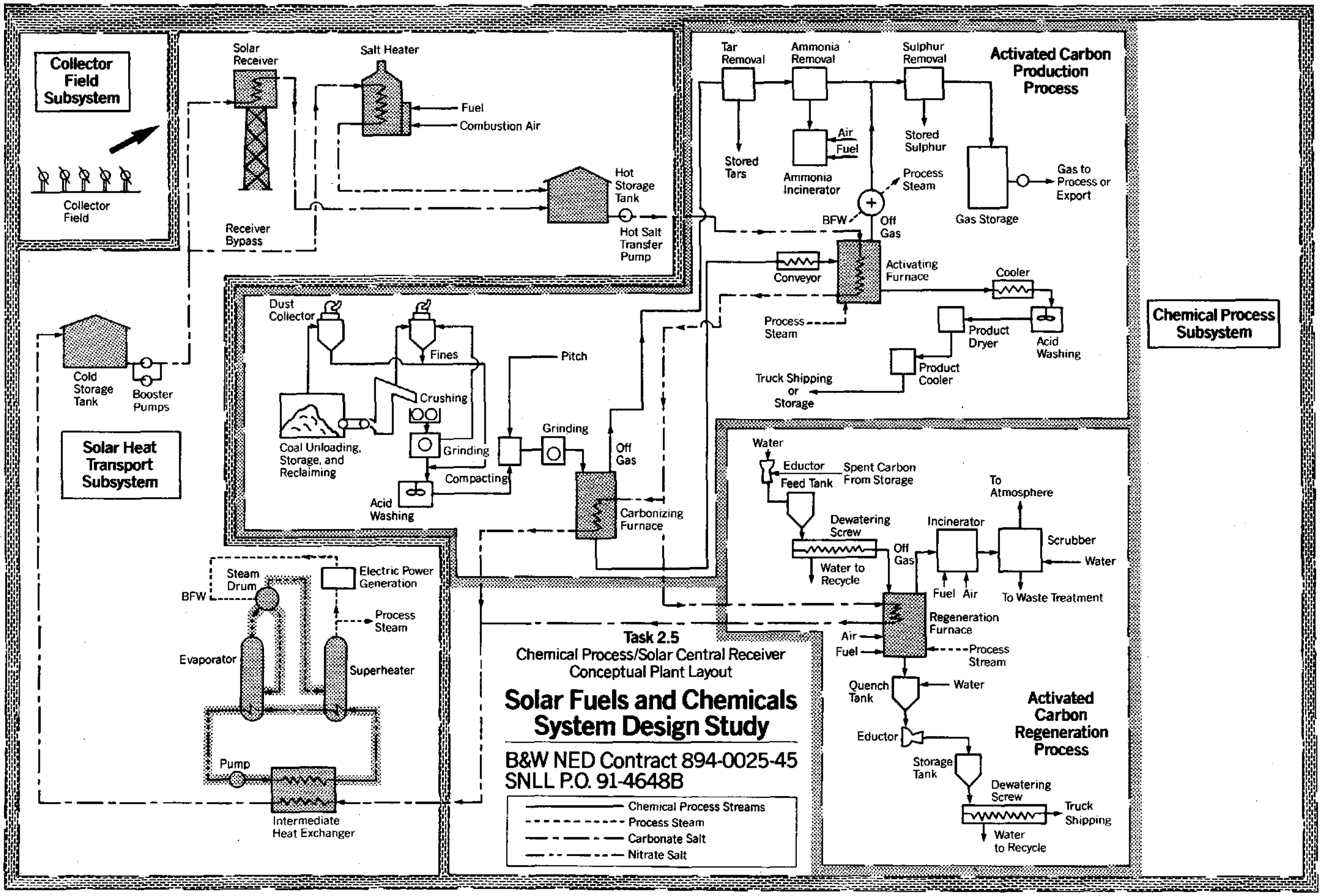
Solar energy input to the receiver in the thermal heat transport subsystem is provided by the collector field subsystem. The collector field is an array of heliostats designed to direct solar radiation to the north-facing receiver cavity located atop the receiver tower. The collector field, tower, and receiver designs must be integrated into a cost-effective arrangement which satisfies the receiver incident heat flux requirements.

The aggressive nature of the molten carbonate salt toward both metallic and ceramic materials at high temperatures resulted in limiting the maximum salt temperature to 954°C (1750°F) and choosing a bimetallic material (Inconel 600 for corrosion resistance and Inconel 617 for strength) to contain the molten salt at high temperatures. Based on the 954°C (1750°F) salt temperature limit, the highest temperature requirements of the regeneration process are met with energy input from fossil fuel.

A conceptual layout of the entire solar fuels and chemicals design for the production and regeneration of activated carbon is shown on Figure 1. The boundaries of the chemical process, solar heat transport, and collector field subsystems are delineated on this figure as are the major equipment, the chemical process streams, and the molten salt streams.

2.1 Chemical Process Subsystem

A process to produce activated carbon and to regenerate spent carbon using energy supplied by a hot molten carbonate salt has been defined. A major portion of the energy to heat the carbonate salt will be supplied by a solar central receiver. A subbituminous coal [141.3 metric tons/day (156 tons/day)], common to the western United States, was chosen as the raw material. Coal tar pitch [15.4 metric tons/day (17 tons/day)] is also required as a binder in pretreatment. Daily production rates of activated carbon and regenerated carbon are 35.3 metric tons (39 tons) and 28.1 metric tons (31 tons), respectively. The major by-products of the process are product gas and tars. The product gas [9487 m^3/hr (335,000 SCFH)] will be used to heat the carbonate salt during the off hours or as required. This gas has a low heating value of 3.23 kwh/m^3 (312 Btu/SCF). Any excess gas may be sold as fuel or chemical feedstock.



Collector Field Subsystem
Collector Field
Solar Receiver
Salt Heater
Fuel
Combustion Air
Hot Storage Tank
Hot Salt Transfer Pump
Receiver Bypass
Cold Storage Tank
Booster Pumps
Solar Heat Transport Subsystem
Tar Removal
Ammonia Removal
Sulphur Removal
Activated Carbon Production Process
Stored Tars
Air
Fuel
Ammonia Incinerator
Stored Sulphur
Process Steam
Gas Storage
Gas to Process or Export
BFW
Off Gas
Conveyor
Activating Furnace
Cooler
Process Steam
Product Dryer
Acid Washing
Product Cooler
Truck Shipping or Storage
Chemical Process Subsystem
Dust Collector
Fines
Crushing
Coal Unloading, Storage, and Reclaiming
Grinding
Compacting
Acid Washing
Pitch
Grinding
Off Gas
Carbonizing Furnace
Steam Drum
BFW
Electric Power Generation
Process Steam
Evaporator
Superheater
Pump
Intermediate Heat Exchanger
Water
Eductor
Feed Tank
Spent Carbon From Storage
To Atmosphere
Dewatering Screw
Incinerator
Scrubber
Water
Off Gas
Water to Recycle
Fuel
Air
To Waste Treatment
Regeneration Furnace
Air
Fuel
Process Stream
Quench Tank
Water
Eductor
Activated Carbon Regeneration Process
Storage Tank
Dewatering Screw
Truck Shipping
Water to Recycle
Task 2.5
Chemical Process/Solar Central Receiver Conceptual Plant Layout
Solar Fuels and Chemicals System Design Study
B&W NED Contract 894-0025-45
SNLL P.O. 91-4648B
Chemical Process Streams
Process Steam
Carbonate Salt
Nitrate Salt

Figure 1

Approximately 27.2 metric tons/day (30 tons/day) of by-product tars are produced. These tars have a low heating value of approximately 9.69 kwh/kg (15,000 Btu/lb). The tars can be burned as fuel or may be sold.

The process to produce activated carbon involves several pretreatment steps to the raw material (coal). After crushing to size, the coal is acid washed to remove acid-soluble ash and destroy the agglomerating properties of the subbituminous coal. The coal is mixed with pitch (which acts as a binder), pulverized, and compacted into pellets. The pellets are reground into granules.

The granules are sent to the carbonization furnace where they are heated to $600^{o}C$ ($1112^{o}F$) in an oxygen-free atmosphere. The volatiles, containing tar, oil, light hydrocarbons, ammonia, and hydrogen sulfide, are removed from the granules and are sent to the tar removal/ammonia removal systems. The granules (char) from the carbonization furnace are sent to the activation furnace where steam is added. The steam reacts with the char to produce extensive internal surface area. This furnace operates at $800^{o}C$ ($1472^{o}F$). The product is cooled, treated with acid to remove surface-deposited ash, dried, and shipped. The off-gases from activation, containing mostly hydrogen and carbon monoxide, are combined with carbonization off-gas and sent to the sulfur removal system. Hydrogen sulfide is removed by physical absorption and then converted to sulfur. Approximately 0.84 tons per day of sulfur are produced. A block diagram for the production of activated carbon is shown on Figure 2.

The regeneration of spent carbon requires several basic operating steps. Wet spent carbon is fed with a dewatering screw to a furnace. The furnace has three distinct stages. First the spent carbon is dried at about $120^{o}C$ ($250^{o}F$). Next the carbon is baked at about $760^{o}C$ ($1400^{o}F$) to volatilize the absorbate thus leaving a carbon deposit on the base carbon. The third and most critical step is reactivation: Steam is added and selectively reacts with the deposited carbon at $954^{o}C$ ($1750^{o}F$). The off-gases are usually incinerated to remove any obnoxious or toxic gases. A simplified flow diagram of the regeneration process is shown on Figure 3.

PRODUCTION OF ACTIVATED CARBON

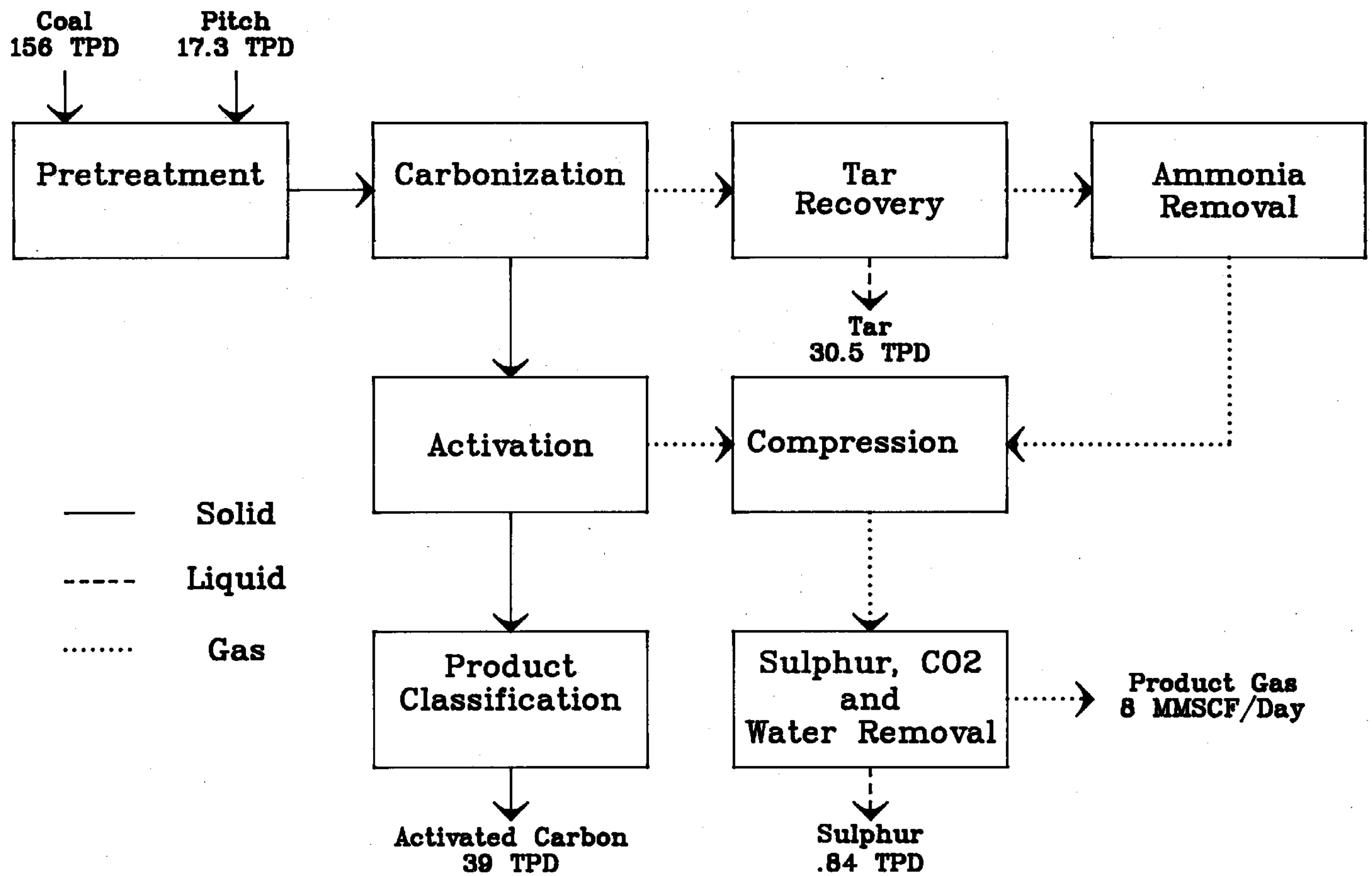


Figure 2

REGENERATION OF SPENT CARBON

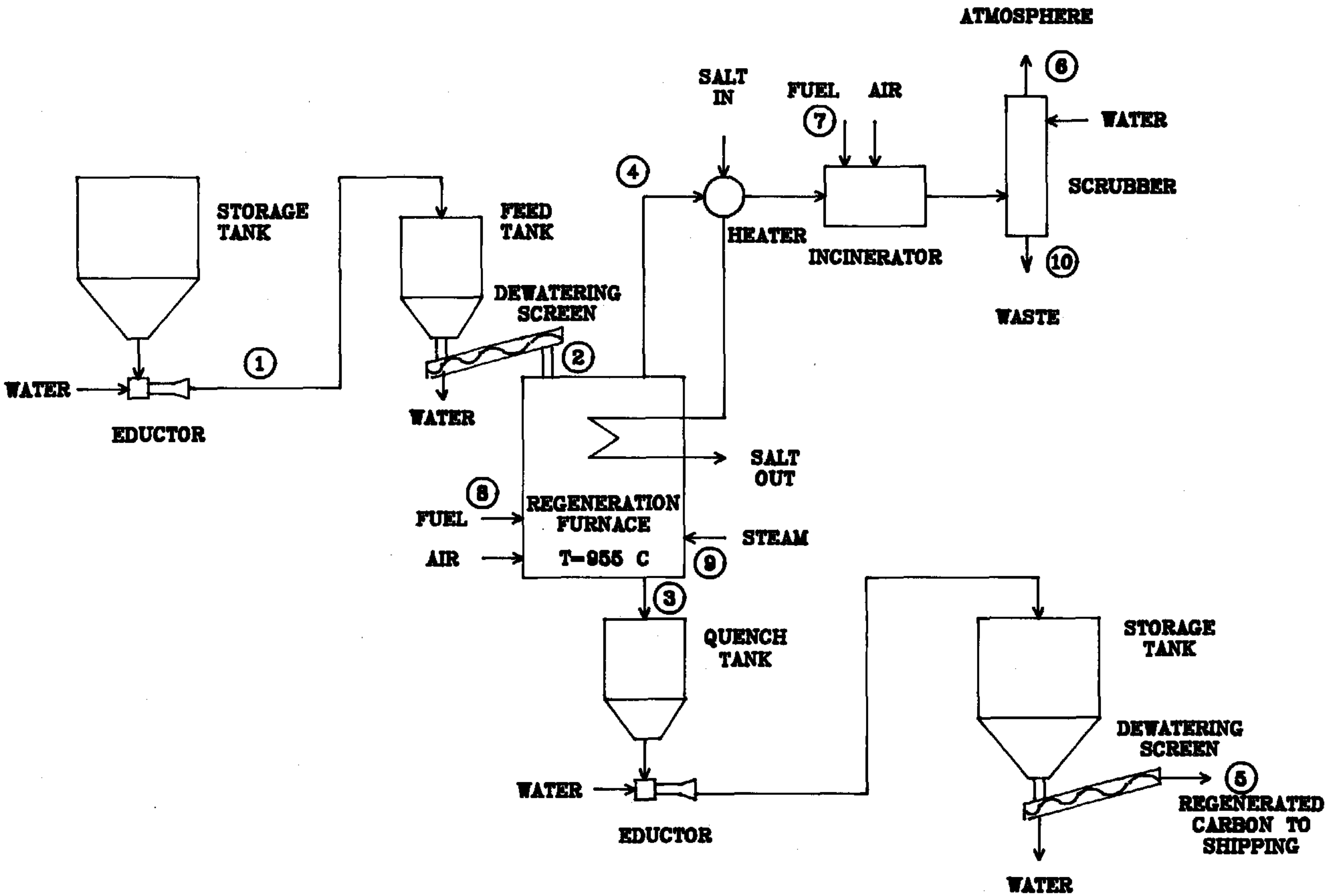


Figure 3

The carbonization furnace and the activation furnace energy requirements will be supplied entirely with molten salt. Because of the high temperatures required for reactivaton, the regeneration energy requirements will be supplied with both molten salt and fuel. Molten salt will supply about 44% of the total energy required for regeneration.

2.2 Solar Heat Transport Subsystem

The solar heat transport subsystem provides energy input to the molten carbonate salt which transports that energy for use in the chemical process subsystem and in the steam generator. The major components and their arrangement within the subsystem are shown on the Conceptual Plant Layout (Figure 1).

The subsystem provides energy input to the carbonate salt on a 24 hour-a-day basis through the use of either the solar receiver or the fossil fired salt heater. During periods of receiver operation, the salt storage tanks decouple the operation of the chemical process from receiver operation. Through a combination of plant operating strategy and receiver sizing, hot salt inventory is accumulated in the hot salt storage tank which permits the continuing operation of the chemical process during cloud transients without the need to cycle the operation of the fossil fired salt heater.

The steam generator portion of the solar heat transport subsystem uses energy input from the carbonate salt to generate steam both for the generation of electrical energy and for the process requirements in the chemical subsystem. The major components of the steam generator subsystem include the intermediate heat exchanger, the evaporator, the superheater, and the steam drum. The intermediate heat exchanger transfers energy from the carbonate salt to an intermediate molten nitrate salt loop. The nitrate salt loop operates at lower temperatures than the carbonate salt, permitting the design of evaporator and superheater heat exchangers which have reasonable salt-to-water temperature differences.

A system of pumps, piping, and valves connects the various components to regulate the flow of molten salt and water/steam through the subsystem and to provide the required salt flow to the chemical process subsystem. These flow paths are shown conceptually on Figure 1. Figures 4 and 5 present the fluid temperatures and flows and the rated heat loads of the components.

2.3 Receiver Tower and Collector Field Subsystem

The heliostat field is typically the most significant cost driver of central receiver systems. Cost effective design of the heliostat field is closely linked to the receiver configuration and receiver operating characteristics. The objective of the conceptual design effort was to develop a heliostat field/receiver interface which minimized the contribution of the heliostat field and receiver tower to the overall system cost of energy.

The solar subsystem (heliostat field size and layout, tower height, and aperture size) was optimized using DELSOL2, a FORTRAN computer code developed by SNLL. DELSOL2 calculates the optical performance and optimal system design for solar thermal central receiver plants. It computes instantaneous and annual system efficiencies for user-defined central receiver systems, stepping through a grid of parametric calculations to select the configuration having the lowest life cycle cost of energy. The goal of the solar design was to minimize the solar contribution to the cost of thermal energy delivered to the base of the receiver tower. Included in the DELSOL2 optimization input were the capital costs of the heliostat field, land and site preparation, tower, and in-tower piping. Operations and maintenance costs of these elements were also included as a multiplier of the respective capital costs.

The approach taken in the solar subsystem design was to first find the optimum tower height/receiver aperture size/heliostat field layout combination without considering flux constraints within the receiver cavity. Following the determination of this optimum configuration, design point flux maps were computed for various alternative arrangements of the receiver cavity and absorption surface. The preferred receiver configuration was chosen based on a comparison of computed and allowable incident fluxes on the receiver absorption surface.

Solar Heat Transport Subsystem Schematic

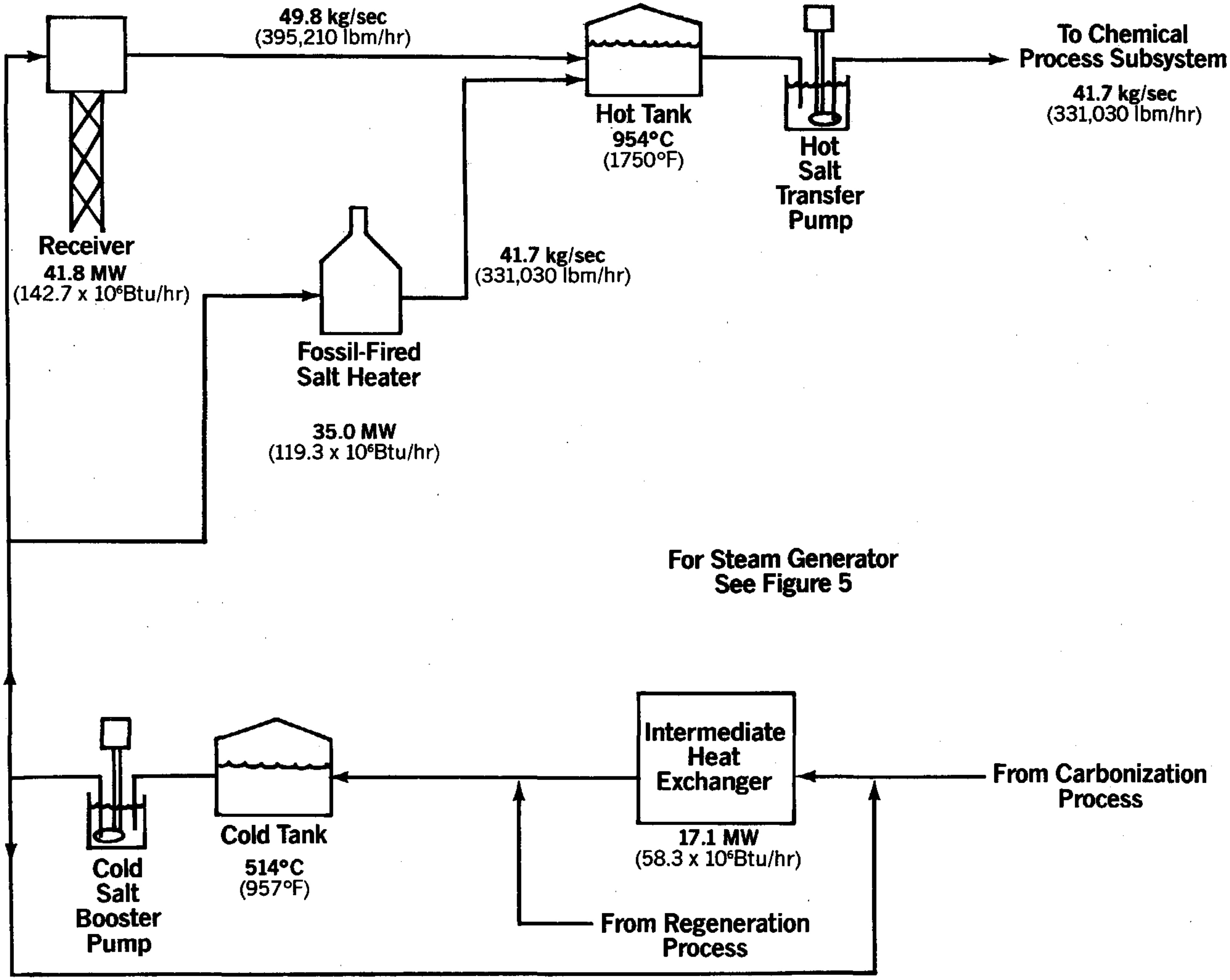


Figure 4

Steam Generator Schematic

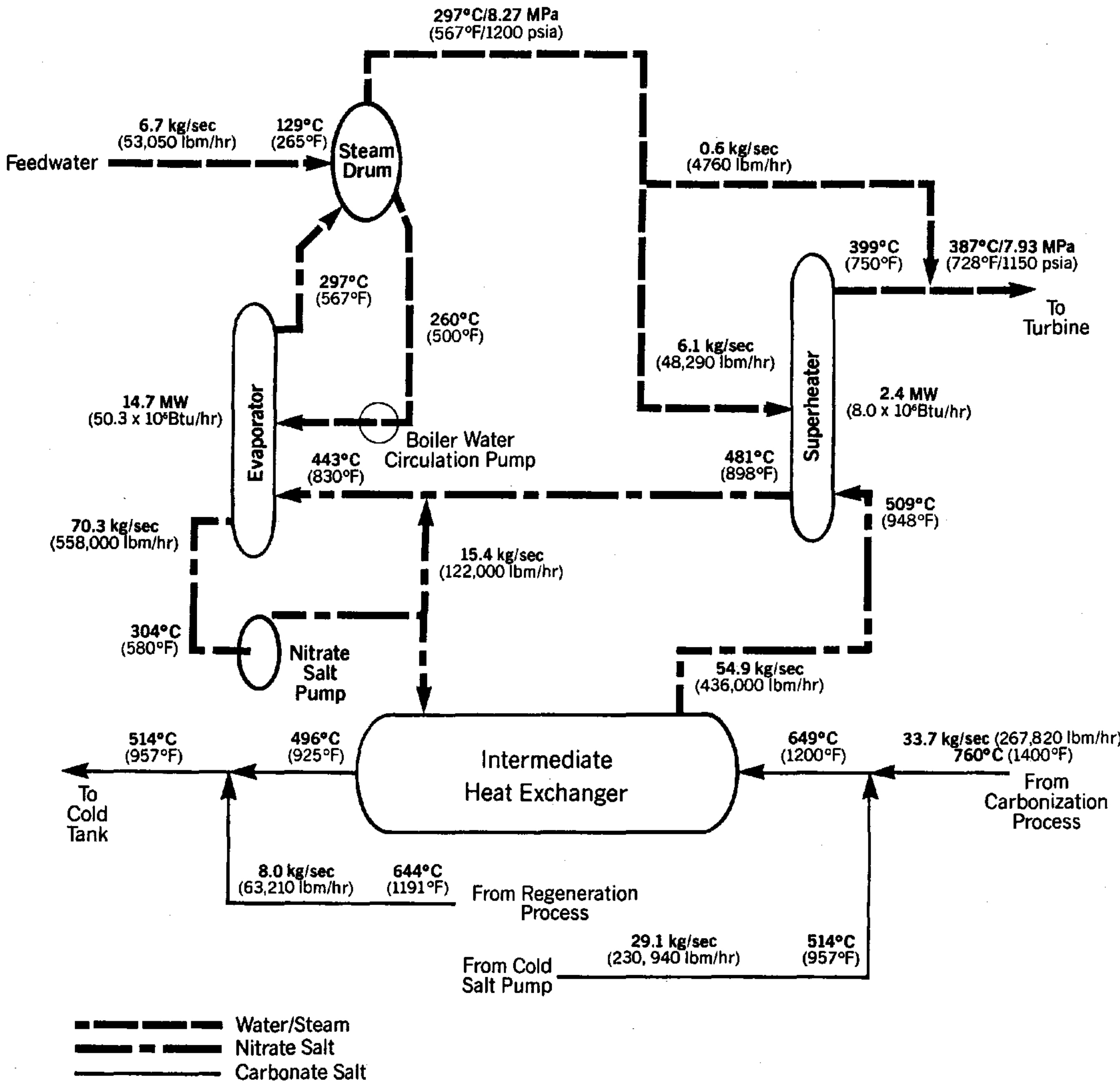


Figure 5

As defined by DELSOL2, the tower height is the distance between the horizontal plane of the pivot of the heliostat and the plane of the center of the aperture. The optimum system has a tower height of 90 m (295 ft) for all but very small apertures. The optimum receiver aperture size is 7.6 m by 7.6 m (25 ft by 25 ft). The tower measures 85.34 meters (280 feet) from ground level to the receiver support elevation. It is a self-supported, braced structural steel frame, rectangular in cross section, with four principal columns. Reinforced concrete footings support the tower columns. Based on these receiver aperture and elevation characteristics, a cost effective heliostat field was designed to achieve maximum annual performance. The optimum heliostat field consists of 797 heliostats, providing a total reflective area of 76,100 m^2 (817,000 ft^2). The field extends radially from the receiver tower a minimum distance of 68 m (220 ft) to a maximum distance of 630 m (2,070 ft), and azimuthally from 31.1 degrees north of west to 31.1 degrees north of east.

2.4 Balance of Plant

Several additional systems support the operation of the solar fuels and chemicals process. These include the Coal Handling System, Electrical Generation System, Water Systems, Storage Systems, and Gas/Product Storage Systems.

The Coal Handling System is designed to provide coal at a rate necessary to meet process requirements, to minimize fugitive particle spread to the solar collector field, and to provide safe operation of the system. Coal arrives by rail at the Coal Unloading Building. Four belt feeders convey the unloaded coal to the receiving end of the elevating conveyor. Coal is immediately weighed and transported to the coal storage silos. The Coal Handling System is designed for manual control under the direct supervision of operating personnel. Appropriate limit switches and safety devices shut off the coal flow in the event of equipment failure, fire, or other emergency conditions. Dust control and fire protection thoughout the system are primary design considerations. Passive dust control includes enclosure of all coal handling equipment and plant areas where coal is being handled. These same areas have active dust control by the use of dust suppression or collection systems. Automatic sprinkler systems provide fire protection.

The Electrical Generation System is designed to provide for distribution of electrical power from off site and on site sources, provide electrical generating capacity from excess process heat for plant electrical requirements, and provide capability to furnish excess electrical power to off site users. The electrical energy is produced by a turbine-generator which is powered by steam from the steam generator. The turbine-generator has a nominal generating capacity of 3 megawatts. The turbine-generator is a package-type unit complete with pressure lubrication system, turbine controls, and other accessories. The turbine exhaust discharges to a surface condenser, where the remaining steam is condensed and the condensed liquid collected for recirculation in the feedwater cycle. Steam is extracted from an intermediate turbine stage for heating and deaeration of feedwater in the deaerator and for use as process steam. The Electric Power Transmission and Distribution System takes the electrical energy produced by the generator and steps the voltage up in the main transformer to the transmission line voltage. The power is then transmitted to the switchgear for interconnection to the utility's power grid. The main auxiliary transformer uses a portion of the generator's output for the powering of auxiliary equipment within the plant. The reserve auxiliary transformer supplies electricity to the facility when the turbine generator is not in operation.

The primary requirement for the design of the Water System is that the system shall incorporate reasonable measures for water conservation. Potable water is provided for drinking and for sanitary use. Water is supplied for use in the various washers, scrubbers, mixing tanks, and other types of equipment in the chemical process systems and for plant service water. Some of this water is combined with other materials in the chemical processes, or is otherwise lost through evaporation, spillage, or other causes. Cooling water is provided to absorb heat rejected by equipment in the chemical process and generation systems. Water is available for fire protection for buildings and equipment. The calculated water requirement from off site for the operation of the plant is 1192 liters per minute (315 GPM).

The plant design provides systems for the storage of coal, water, and the process products. The primary criteria for the Coal Storage System are to contain an eight day supply of coal, prevent the spread of coal dust to the atmosphere, and provide for fire protection. The Coal Storage System consists primarily of the four coal storage silos, each capable of storing approximately 680 metric tons (750 U.S. tons) of coal.

Coal is loaded into the storage silos from the Coal Handling System by the silo fill conveyors. System discharge is designed for automatic control in conjunction with Coal Pretreatment System operation. Safety devices shut off the coal flow in the event of equipment failure, fire, or other emergency conditions. Dust control and fire protection throughout the system are primary considerations. Passive dust control includes enclosure of all coal handling equipment and areas where coal is being handled. Active dust control includes dust suppression or collection systems.

Water storage systems provide sufficient inventory of water to allow extended uninterrupted operation of the plant in the event of loss of the offsite water supply. The process Water Storage Tank provides sufficient storage to meet the water requirements of the chemical process systems for 12 hours of continuous operation. Water is provided to the tank from the offsite water supply system. Makeup water storage for the Cooling Water System is provided by the Recycled Water Storage Tank. Treated water from the Wastewater Treatment System is pumped into the tank for use as makeup to the cooling tower basin. Water for fire protection is stored in the fire water tank. Storage volume is in accordance with NFPA regulations.

Off-gas produced as a by-product by the chemical process systems is collected and used for fuel for the fossil fired salt heater. During each day, for a period of approximately eight hours, the required heating of the Salt Transport System is provided by the solar receiver, and the salt heater is not used. During this eight hour period, the off-gas produced is stored in one of two Gas Storage Vessels.

Loading silos are provided for both activated carbon and regenerated carbon. The silos are elevated for gravity discharge into trucks for shipment.

2.5 System Operation and Control Strategy

The operation and control strategy of the Chemical Process Subsystem, the Solar Heat Transport Subsystem, and the Collector Field Subsystem must be integrated to assure proper overall plant operation. The operation and control of the Chemical Process and Solar Heat Transport Subsystems were evaluated for various operating modes; the operation of the Collector Field was specifically excluded from the workscope of this contract.

Operating strategies for start-up, shutdown, and normal operation were developed for both the Chemical Process and Solar Heat Transport Subsystems. During periods of solar receiver operation, the thermal storage tanks effectively decouple the operation of the chemical process from the receiver operation. This permits continual operation of the chemical process without the need to cycle the operation of the fossil fired salt heater. During periods of salt heater operation, the fossil fuel firing rate is controlled to match the demand of the chemical process. Detailed process control diagrams for the entire plant were developed to indicate the control loops in the plant and the instrumentation required to support process control.

2.6 Overall System Performance

Overall system performance was evaluated both on an instantaneous basis at the plant rated power design point and on an annual basis. Specific characteristics considered in evaluating the plant performance were the solar-to-thermal efficiencies, chemical process and regeneration energy input requirements, system thermal losses, plant electrical demands, process material input requirements, activated carbon and regenerated carbon production, by-product gas and tar production, and electrical energy production.

The overall system performance was evaluated on an annual basis to estimate the plant's raw material and energy input requirements and its revenue-producing product and energy output. This information is an important consideration in performing the economic assessment of the plant. Based on preliminary assessments of and projections for the activated carbon market, a plant designed for a yearly output of 11,340,000 kg (25,000,000 lbm) of virgin activated carbon and 9,070,000 kg (20,000,000 lbm) of regenerated activated carbon was selected. On the basis of production rates of 0.410 kg/sec (3250 lbm/hr) for virgin activated carbon and 0.328 kg/sec (2604 lbm/hr) for regenerated carbon, the plant operates the equivalent of 320 days per year at rated load. Of the remaining 45 days in the year, 14 days are allocated to scheduled maintenance outage with the other 31 equivalent days given over to lost production due to occurrences such as forced maintenance outages, start-ups, and shutdowns. Energy and production estimates were made for each of these three periods to determine the annual estimate.

The annual solar energy contribution to plant operation is 80,890 MWh (276,100 x 10^6 Btu). The difference between by-product gas produced and fossil fuel required by the process results in a net annual fossil fuel input of 21,300 MWh (72,600 Btu). After considering the electrical energy used by the plant on an annual basis, an annual net of 8,500 MWh of electrical energy is exported from the cogeneration portion of the plant. Table 1 summarizes the energy and raw material inputs and revenue-producing product and energy outputs on an annual basis.

TABLE 1

Annual Energy and Product Production Projection

	Scheduled Outage (336 hr)	Lost Production (744 hr)	Rated Load Operation (7680 hr)	Annual (8760 hr)
Input				
Solar, MWh				80,890
(10^6 Btu)				(276,100)
Fossil fuel, MWh		291	256,300	256,600
(10^6 Btu)		(992)	(874,900)	(875,900)
Electricity, MWh	75.6	372	14,090	14,540
(10^6 Btu)	(258.0)	(1270)	(48,090)	(49,630)
Coal, kg			45,280,000	45,280,000
(lbm)			(99,840,000)	(99,840,000)
Pitch, kg			5,029,000	5,029,000
(lbm)			(11,090,000)	(11,090,000)
75% H_3PO_4, kg			512,500	512,500
(lbm)			(1,130,000)	(1,130,000)
30% HCl, kg			1,139,000	1,139,000
(lbm)			(2,512,000)	(2,512,000)
Spent Carbon, kg			13,370,000	13,370,000
(lbm)			(29,480,000)	(29,480,000)
Output				
Activated Carbon, kg			11,350,000	11,350,000
(lbm)			(24,960,000)	(24,960,000)
Regenerated Carbon, kg			9,070,000	9,070,000
(lbm)			(20,000,000)	(20,000,000)
Tar, kg			8,857,000	8,857,000
(lbm)			(19,530,000)	(19,530,000)
By-Product Gas, MWh			235,300	235,300
(10^6 Btu)			(803,200)	(803,200)
Electricity, MWh			23,040	23,040
(10^6 Btu)			(78,640)	(78,640)

3.0 ECONOMIC ASSESSMENT

An economic assessment of the solar powered fuels and chemicals plant was performed to determine internal rates of return as a function of fuel/feedstock and product price escalation. Capital costs were compiled using the Cost Data Management System developed by Polydyne Inc. for Sandia National Laboratories. Annual operation and maintenance costs are estimated to be $12,069,000. The breakdown of the plant capital costs are as follows:

		Dollars	%
0	Land	$ 3,735,200	4
1	Structures & Improvements	8,166,000	10
2	Power Generation System	32,868,963	38
4	Cogeneration Plant	2,869,655	3
5	Process Plant Systems/Equipment	24,557,800	29
9	Plant Level--Indirect Costs	13,699,000	16
	Total Capital Requirement	$85,896,618	100

A market forecast was performed to project future demand and supply of granular activated carbon (GAC). The U.S. demand for GAC is projected to grow at an annual rate of 5.6% through 1988 and then slow to a long-term growth rate through the year 2000 of approximately 3%. GAC appears to be in a relatively mature position along its product life cycle with a few short-term opportunities, but also with considerable long-term uncertainty. At present, the U.S. capacity for producing activated carbon exceeds demand by approximately 35%. Since it appears unlikely that demand will surpass industry capacity before the year 2000, a solar GAC plant would most likely have to be the lowest cost producer by a significant margin in order to gain meaningful market penetration.

The internal rate of return was determined assuming 1) full capacity production, 2) 20 year plant life, and 3) zero general inflation rate. For comparison purposes, the rate of return was also determined for a natural gas fueled chemical plant. The following table lists the results for 0% and 3% annual escalation rates of fuel/feedstock costs and product selling prices.

	Escalation Rate	Internal Rate of Return
Solar Plant	0%	11.0%
	3%	14.9%
Gas Plant	0%	20.1%
	3%	23.7%

In conclusion, an escalation rate of 0.9% on fuel/feedstock and product selling prices allows the solar powered chemical plant to surpass the 12% hurdle rate for the chemical industry. However, for the solar plant to compete with the gas plant, high escalation rates combined with cost reductions in the solar plant are needed. Further analysis shows that if the long-term component cost goals listed in the National Solar Thermal Technology Program Five Year Research and Development Plan 1986-1990 (45) are obtained, the solar powered chemical plant can be competitive with the natural gas plant assuming moderate escalation rates.

4.0 TECHNOLOGICAL UNCERTAINTIES

The technological uncertainties uncovered during the design phase of this contract identify those areas of concern that require additional evaluation/testing to further develop the activated carbon production process. To address these technical concerns, a development plan is utilized. Two categories of technical concern evolved within the development plan. The first includes those technical uncertainties that are key issues in the design, construction, and operation of this facility. Development in these areas is essential to construct a functioning facility. The second incorporates technical uncertainties that have a cost impact. These areas of concern could be developed for cost savings, but, would not prevent a test facility from operating. The key issues will be referred to as technical hurdles while those uncertainties with a financial impact will be called economic hurdles. In addition to considering the hurdles for the 954^{o}C (1750^{o}F) maximum salt temperature of the present design, ceramic development for a salt temperature of 1150^{o}C (2100^{o}F) is considered. The use of this higher salt temperature would eliminate the need to power a portion of the regeneration process with fossil fuel. The technical issues are grouped as follows:

	954°C (1750°F) Service	1150°C (2100°F) Service
Technical Hurdles	1-Material Development 2-Salt Properties Development 3-Component Development	Ceramic Development
Economic Hurdles	1-Receiver Thermal Losses 2-Controls & Operating Strategy	Not Evaluated

4.1 <u>Material Concerns</u>

Material uncertainties begin with the lack of long term confidence in Inconel 600 as a containment material. The main concern with Inconel 600 is its long term resistance to the corrosive carbonate salt. A second uncertainty, which hampers the design of the high temperature components, is limited creep and fatigue data for Inconel 617 at the required temperatures. These materials may be adequate for the components designed in this study, but further testing is required for confirmation.

4.2 <u>Salt Properties</u>

The data base for molten carbonate salt is weak. Conflicting and limited data is evident throughout the required temperature range. In addition, long-term stability of carbonate salt at high temperatures is not well understood. This behavior must be better established to determine requirements for cover gas, salt purification, and/or periodic salt replenishment.

4.3 <u>Component Design</u>

The components in question are the pumps, valves, and chemical reaction furnaces. The pumps and valves are essential and are exposed to the salt's harsh environment at all temperature ranges. Internal pump and valve components that contact the molten salt are areas of uncertainty. The chemical reaction furnaces in the conceptual solar plant design employ conductive and radiant heat in the production of activated carbon rather than the conventional open flame convection utilized at present by the industry.

Verification of product quality would require laboratory and pilot scale tests to study important operating parameters such as conductive and radiant heat transfer rates, temperature gradients, off-gas composition, and reaction times. Additional reaction furnace concerns involve materials of construction and mechanical design.

4.4 Ceramic Development

The design study did not pursue the 1150°C (2100°F) service due to failure to locate an adequate molten salt-compatible material. Return to the 1150°C (2100°F) salt temperature hinges on the development of a containment material. This extreme temperature requires the development of a corrosion resistant ceramic with suitable strength properties.

4.5 Economic Hurdles

Two technical issues with an economic impact are receiver thermal losses and controls and operating strategy. The uncertainty of receiver thermal losses involves accurate determination of the quantity and source of lost energy. A better understanding of the sources of receiver thermal loss would allow for design of a more efficient receiver resulting in the reduction of the heliostat field. The concerns associated with the controls and operating strategy are instrumentation design, system logic, and system integration. Development in these areas could reduce fabrication costs and increase component life expectancy in addition to reducing plant operating expenses.

4.6 Technical Maturity

The proposal objective was to select an established chemical process that was energy intensive and could utilize a solar central receiver as its energy source. The process for the production of activated carbon was selected, in part, due to its longevity as a commercially produced product. This process is technically mature and does not pose any significant technical risks. Integration of this chemical process with a solar plant required the alteration of standard chemical reaction furnaces. This deviation creates the only area of technical concern in the chemical plant. The design and projected performance of each solar plant component reflects a high level of confidence that a functioning plant is possible. All areas that reduce confidence in the solar plant stem from containment, transportation, and control of the high temperature carbonate salt.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The Solar Fuels and Chemicals System Design Study has provided B&W's project team a vehicle to apply their combined expertise toward evaluating both technical and economic feasibility of a new application of solar thermal central receiver technology. The project plan was structured to provide a balance of information requiring development to support the technical and economic conclusions which follow.

5.1 Conclusions

THE EXTENSION OF SOLAR THERMAL CENTRAL RECEIVER TECHNOLOGY TO HIGHER TEMPERATURES IS FEASIBLE.

The carbon production process as originally envisioned required 1150°C (2100°F) carbonate salt. The inability to find a suitable containment material (ceramic or metallic) necessitated modifying the process to partially heat the spent activated carbon with gas. This lowered the required hot salt temperature to 955°C (1750°F).

At this intermediate salt temperature, the design of major components has not deviated from existing methods and design practice with the exception of the receiver panels. Co-extruded tubes (Inconel 600 for salt containment; Inconel 617 for strength) are used because Inconel 600 by itself does not have the required strength at these elevated temperatures.

Existing corrosion and material property data generally support the choice of Inconel 600 as a salt containment material. However, additional corrosion testing is essential to confirm the selection and establish the required corrosion allowances.

Additionally, although estimates of creep data for Inconel 617 have been made and are believed conservative, this property data must be developed.

AS ADVANCED CONCEPTS/APPLICATIONS MOVE TOWARD HIGHER TEMPERATURES, THE HEAT TRANSPORT SUBSYSTEM BECOMES A MORE SIGNIFICANT COST CONTRIBUTOR TO CAPITAL COSTS THAN THE COLLECTOR FIELD.

- -

Cost reduction effort in solar central receivers has historically emphasized development of low cost heliostats because the field was the major cost contributor. Benefits of this strategy are visible in this study in using a $60/m^2 cost for stressed-membrane heliostats. It becomes obvious in reviewing the capital cost summary that the heat transport subsystem is the relatively largest cost contributor. This results from more expensive materials and design features to accommodate high temperature.

Additionally, the carbonate salt was chosen as a working fluid due to its characteristics at elevated temperatures. This imposes significant restrictions on choice of materials for compatibility. Materials testing and development will need to receive the same high priority attention that has benefitted heliostat development.

THE CONCEPT DEVELOPED HAS THE POTENTIAL FOR EXCEEDING THE HURDLE RATE FOR THE CHEMICAL INDUSTRY.

- -

The hurdle rate is the rate of return necessary to attract investment capital to a particular venture. It is determined on the basis of risk and alternatives and is typically 12% for the chemical process industry. Our evaluation shows a 11.0% rate of return based on total costs and revenues and a 0% escalation rate (on feedstock, fuel, and product). The 12% hurdle rate can be met if a 0.9% escalation rate occurs,or a 18% cost reduction in the solar portion of the plant capital costs can be realized.

AS CURRENTLY CONFIGURED, THE SOLAR FACILITY RATE OF RETURN DOES NOT COMPARE FAVORABLY WITH A GAS FIRED FACILITY WITHOUT SIGNIFICANT ESCALATION OF GAS AND ELECTRICITY PRICES AND CAPITAL COST REDUCTIONS.

- -

After showing that the solar activated carbon producing plant could meet the 12% hurdle rate with modest escalation and capital cost reduction, a comparative evaluation was made to a gas-fired facility. A comparable rate of return can be achieved but only through the benefits of both a higher escalation rate (10%) and the achievement of all the cost reduction goals of the 1986-1990 Five Year R&D Plan of the National Solar Thermal Technology Program (Ref. 45). This combination constitutes a very optimistic approach to the overall solar/fossil comparison.

THE GRANULAR ACTIVATED CARBON (GAC) MARKET FORECAST IS CHARACTERIZED BY SLOW GROWTH AND UNCERTAINTIES.

- -

The GAC market is projected to grow at 5.6% through 1988 and slow to a longer term rate of 3% through 2000. The "most likely" environment suggests that existing capacity will be underutilized through 2000. This increases emphasis on cost reduction and energy price escalation to justify continuing development of the process. Uncertainties are a result of unpredictable worldwide energy outlook, legislative changes affecting the environment and technological advancements in competing products.

5.2 Recommendations

This conceptual design study as originally proposed was the first phase of a multiphase program envisioned to bring the application of solar central receiver technology and chemical production to commercialization. Subsequent phases included:

- o Advanced conceptual design
- o Bench scale laboratory tests
- o Component design and development
- o Subsystem research experiment
- o Pilot plant

The activated carbon production process was chosen because it was an energy intensive process, it required improvements to existing technology, it had economic potential, and it was amenable to frequent startups/shutdowns of a solar facility. The conclusions reported in Section 5.1 alter the above scenario for development of this process. Recommendations for continued development follow.

A DECISION TO CONTINUE DEVELOPMENT OF THE ACTIVATED CARBON PRODUCTION PROCESS SHOULD BE BASED ON AN IMPROVED OVERALL ECONOMIC PICTURE.

- -

Although the concept has been shown to be technically feasible and it has the potential for meeting the hurdle rate for the chemical industry, it does not currently compare favorably with a gas-fired facility. A significant escalation in gas prices and/or decrease in solar plant capital costs are essential to improving solar's economic position. Additionally, the market forecast projects only a small long term annual growth (3%). The forecast may be significantly impacted by environmental legislation, technological innovations, and the projections for energy growth. Based on the current economic picture, development of the solar powered granular activated carbon production and regeneration process should be discontinued.

EVALUATION OF FUTURE SOLAR FUELS AND CHEMICALS APPLICATIONS MUST CONSIDER THE IMPACT OF HIGH TEMPERATURE ON THE PROCESS AND THE PROCESS ECONOMICS.

This study has concluded that the solar heat transport subsystem capital costs have become the single most significant contributor to the total plant capital costs. The advantages of higher temperature operation to potentially improve system efficiency and the basic need for higher temperatures to operate a fuels and chemicals production process must be balanced against high capital costs which could render a given process uneconomical. Caution must be exercised in choosing and evaluating future applications of solar energy to fuels and chemicals processes.

EMPHASIS SHOULD BE PLACED ON PERFORMING "UP-FRONT" ECONOMIC EVALUATIONS OF FUTURE PROPOSED FUELS AND CHEMICALS APPLICATIONS

The economic results of the study of the production and regeneration of activated carbon indicate the need to place emphasis on "up-front" economic evaluations of other potential fuels and chemicals processes prior to embarking on preliminary conceptual plant design studies. Using the base of technical and economic information developed in fuels and chemicals economic studies performed to date, "ballpark" economic evaluations of other intermediate or high temperature processes can be made to estimate their economic viability, prior to proceeding with a preliminary conceptual design study of a given process.

Should the decision be made to continue development of solar fuels and chemicals technology, the following recommendations should be considered.

ADDITIONAL BASIC RESEARCH SHOULD BE PURSUED IN THE AREAS OF SALT CHEMISTRY AND MATERIAL COMPATIBILITY

Existing corrosion and material property data generally support our design selection decisions, but the data base is not sufficient to proceed with a more detailed design phase. A broader data base of carbonate salt properties is needed that includes salt stability characteristics at elevated temperatures. Corrosion testing of a wider range of candidate materials is also needed. These tests should include effects of altering the salt chemistry and the presence/absence of oxygen or other cover gases. Methods of testing must be rigorous. This testing is essential to the pursuit of higher temperature systems using carbonate salts.

SPECIFIC COMPONENT STUDIES COULD BE PURSUED

While efforts will continue to identify potential new applications for central receiver technology, specific component studies could be pursued. Based on the selection of an advanced heat transport medium for high temperatures (e.g. carbonate salt), component studies on receivers, storage tanks, and pumps and valves would be timely and valuable if geared toward cost reduction goals. The viability of central receiver technology will ultimately be decided by economics. Such studies could be pursued independent of the chemical process.

UNLIMITED RELEASE
INITIAL DISTRIBUTION

U.S. Department of Energy (5)
Forrestal Building
Code CE-314
1000 Independence Avenue, S.W.
Washington, D.C. 20585
Attn: H. Coleman
       S. Gronich
       F. Morse
       M. Scheve
       R. Shivers

U.S. Department of Energy
Forrestal Building, Room 5H021C
Code CE-33
1000 Independence Avenue, S.W.
Washington, D.C. 20585
Attn: C. Carwile

U.S. Department of Energy
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, NM 87115
Attn: D. Graves

U.S. Department of Energy
San Francisco Operations Office
1333 Broadway
Oakland, CA 94612
Attn: R. Hughey

University of California
Environmental Science and Engineering
Los Angeles, CA 90024
Attn: R. G. Lindberg

University of Houston (2)
Solar Energy Laboratory
4800 Calhoun
Houston, TX 77704
Attn: A. F. Hildebrandt
       L. Vant-Hull

Analysis Review & Critique
6503 81st Street
Cabin John, MD 20818
Attn: C. LaPorta