GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT TERMINATION

Date: October 11, 1980

Project Title: Systems-Integration Requirements for the Synergistic Co-Siting of Industrial Activities

Project No: B-488

Project Director: Dr. Jack M. Spurlock

Sponsor: National Science Foundation

Effective Termination Date: 4/30/80 (Grant Period)

Clearance of Accounting Charges: - - - - - -

Grant/Contract Closeout Actions Remaining:

_ Final Invoice and Closing Documents
X Final Fiscal ~~Report~~ Accounting (FCTR)*
X Final Report of Inventions
_ Govt. Property Inventory & Related Certificate
_ Classified Material Certificate
_ Other ____________

*EES Accounting: Please notify OCA/NSM so Budget Amendment can be submitted to zero-out project.

Assigned to: CM/OD (School/Laboratory)

COPIES TO:

Project Director
Division Chief (EES)
School/Laboratory Director
Dean/Director–EES
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Procurement Office
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Library, Technical Reports Section
EES Information Office
Project File (OCA)
Project Code (GTRI)
Other Mr. F. H. Huff (Info.)

A–4 (1/79)

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: May 31, 1977

Project Title: Systems-Integration Requirements for the Synergistic Co-Siting of Industrial Activities

Project No: B-488

Project Director: Dr. Jack M. Spurlock

Sponsor: National Science Foundation (NSF/RANN)

Agreement Period: From 4/15/77 Until ~~9/30/79~~ 30 Apr 80

(24-month budget period plus flexibility period)

Type Agreement: Grant No. ~~AER~~ IPR76-80993

Amount: $199,700 NSF
10,000 GIT (E- -- to be assigned after 7/1/77)
$209,700

Reports Required: Interim Progress Reports; Final Technical Report; Summary of Completed Project

Sponsor Contact Person (s):

Technical Matters

Contractual Matters
(thru OCA)

Ms. Mary Frances O'Connell
Grants Administrator
National Science Foundation
Washington, DC 20550
(202)632-2858

Defense Priority Rating: None

Assigned to: Applied Sciences Laboratory (School/Laboratory)

COPIES TO:

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School/Laboratory Director	Director, Physical Plant
Dean/Director—EES	EES Information Office
Accounting Office	Project File (OCA)
Procurement Office	Project Code (GTRI)
Security Coordinator (OCA)	Other
Reports Coordinator (OCA) ✓	

-3 (3/76)

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

October 14, 1977

Grants Administrator
National Science Foundation
Washington, D.C. 20550

Attention: Ms. Mary Frances O'Connell

Reference: NSF Grant No. AER76-80993
(Georgia Tech Project No. B-0488-000)

Subject: Interim Progress Report No. 1
"Systems-Integration Requirements for the Synergistic Co-Siting of Industrial Activities"

This report summarizes progress on the referenced grant project for the period April 15, 1977 through October 14, 1977.

I. Introduction

The purpose of this program is to apply advanced and comprehensive systems-integration methodology for the design of cost-effective, synergistically co-sited industrial activities. Synergistic co-siting involves the carefully planned grouping of industrial and/or agricultural activities in complexes that provide mutually beneficial utilization of energy, raw materials, co-products, land, plant wastes, and transportation facilities, as well as promote greater economical attractiveness of pollution-control measures, resource recovery, etc. Anticipated results of this study include practically achievable synergistic co-siting approaches to industrial-site planning, and to plant and process design, which offer the promise of some very effective and exciting possibilities for the simultaneous achievement of certain critical national and international goals such as resources (including energy) conservation, new energy sources, effective land use, improved food supply, improved environmental quality, and beneficial industrial development. These results, together with guidelines and recommendations for their practicable application, will be communicated appropriately to prospective users during the course of this study.

The rationale for our study involves a systematic search for, and evaluation of, industrial combinations which offer promise for grouping synergistically in some form of co-siting to satisfy total systems-integration criteria and accomplish program objectives. Our overall plan consists of a logical sequence of tasks designed to group functionally the investigative activities and facilitate the flow of the associated effort and results among these tasks. The tasks and their individual technical purposes are as follows:

Task I. Expansion of Data Base.

Purpose: To compile adequate technical and economic information required as a basis for the extensive analyses that will be performed on subsequent tasks, including the addition of input-output information on more production commodities as an expanded reservoir of grouping candidates.

Task II. Development of Criteria for Total Systems Integration.

Purpose: To establish guidelines for screening and selecting candidate process units, as required in the coupling-matching analysis, based on realistic benefit goals and systems-integration constraints.

Task III. Coupling-Matching Analysis.

Purpose: To provide candidate industrial couplings for use in developing integrated, synergistically co-sited systems designs, based upon the guidelines formulated in Task II.

Task IV. Systems Integration Analysis.

Purpose: To formulate and specify design features for fully-integrated co-siting complexes which meet the Task II guidelines.

Task V. Tradeoff and Cost-Benefit Analysis.

Purpose: To evaluate realistically the practical advantages and disadvantages, institutional barriers and implementational potential for each of the candidate complexes identified and characterized on Task IV, as a basis for motivating user interest and initiative in pursuing demonstration development of such complexes.

Task VI. Regional Application Analysis.

Purpose: To identify and characterize any features of regional (i.e., geographic, socio-economic, etc.) specificity which favor or exclude certain types of co-siting complexes or individual industrial activities, as a basis for categorizing general and limited applicability of the results and methodology of this program.

Task VII. Formulate Recommendations and Conclusions.

Purpose: To develop and organize a set of useful guidelines for the application of the results and methodology produced on this program of research.

Task VIII. Initiate Utilization Plan.

Purpose: To develop and implement a vigorous, effectual time-phased activity of identifying and communicating with user groups in an effort to (1) disseminate the concepts, evaluational results and significant new industrial-development tools produced on this program, and (2) maximize the benefit potential and usefulness of these program products in as large a user community as possible.

Task IX. Prepare Final Report.

Purpose: To document the procedures, results, conclusions and recommendations of the program in an effective manner and appropriately time-phased to meet the reporting requirements of the National Science Foundation.

The interrelationships among these tasks are shown in Figure 1.

II. Project Schedule and Budget Status

The project effort is currently on schedule and operating within the budget plan. During the first month of the program, the schedule plan was revised somewhat from the plan presented in the original proposal for this grant. These revisions, structured to provide a better flow and coupling of certain task efforts, consisted of the extension of effort on both Tasks II and III from six to nine months each. The revised schedule plan is shown in Figure 2.

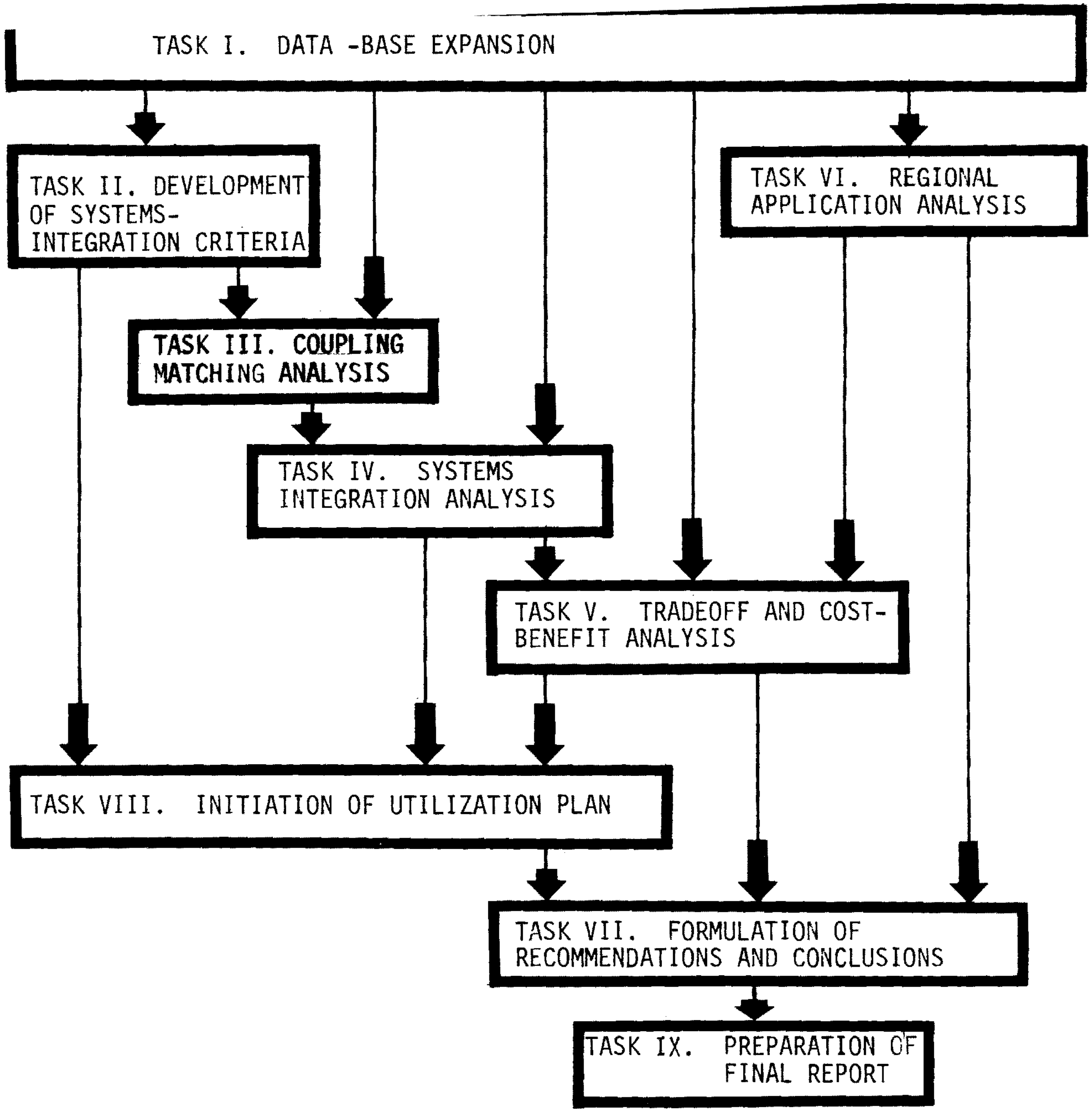

Figure 1. Task Interrelationships.

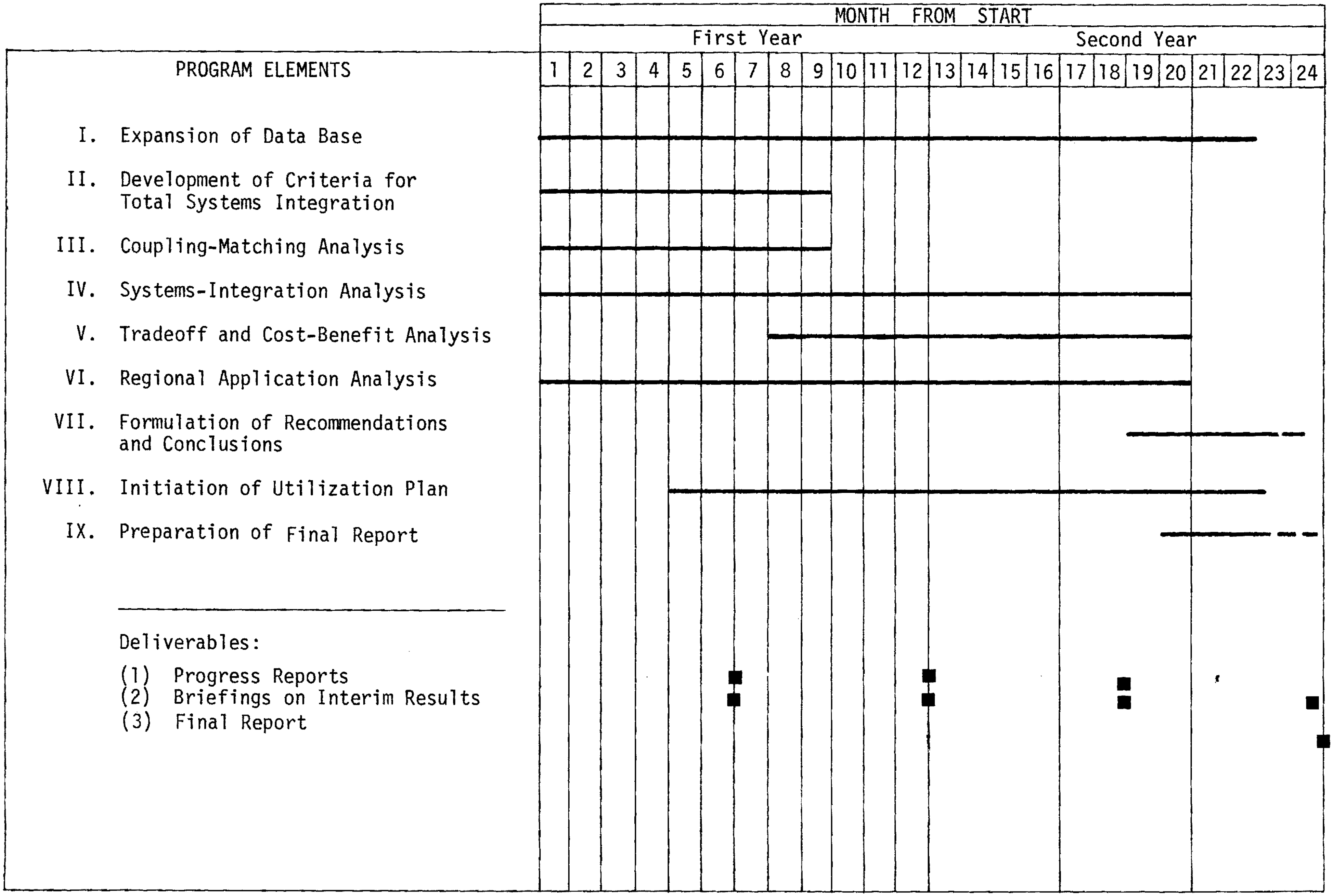

Figure 2. Program Schedule.

Budget status is as follows:

(1)	Total Expenditures to Date:	$40,622
(2)	Expenditures by Categories:	
	(a) Salaries of Principal Investigators and other Senior Personnel--	$11,995
	(b) Other Direct Personal Services--	$10,736
	(c) Material and Supplies--	$ 448
	(d) Travel (Domestic only)--	$ 557
	(e) Computer Services--	$ 116
	(f) Overhead and Benefits--	$16,770
(3)	Total Grant Funds Remaining:	$159,078

III. Technical Progress to Date

Technical progress during the first six-month reporting period of the project is summarized below, by tasks, for those task items that were scheduled for activity according to the schedule plan shown in Figure 2.

Overall Progress Summary

Effort was initiated on Tasks I, II, III, IV, VI, and VIII (described in Section I of this report). All these efforts are on schedule and are providing the anticipated results to date. Tasks I, II, III, and IV are providing the information and basis required for the selection of several technically feasible candidate co-siting groupings; in addition, these tasks are producing a general methodology for such a preliminary selection process. Task VI is providing information on local factors that affect the selection and use of land for various types of industrial sitings. These factors include costs; availability of utilities, labor force, and transportation; environmental constraints and community impact. Task VIII is providing extensive contacts and communication links with industry, federal, state, and local agencies, industrial developers and planners, and other potential user groups.

Capsule summaries of important elements of progress on each initated task are presented below.

Task I. Expansion of Data Base

- Compilation of labor costs for industrial processes
- Compilation of land requirements for industrial processes
- Compilation and correlation of energy requirements of industrial processes
- Compilation of conversion factors and yields of industrial processes
- Alphabetizing of data-base commodities
- Compilation of state-of-art pollution control equipment costs
- Compilation of safety requirements of industrial processes
- Compilation of waste products of industrial processes
- Compilation of pollutants of industrial processes
- Compilation of pertinent EPA regulations for industrial processes

Task II. Development of Criteria for Total Systems Integration

- Compilation and analysis of flow sheets to identify matching interfaces
- Consideration of interfaces based on pollutant utilization schemes
- Consideration of interfaces based on fuel and energy utilization schemes

- Consideration of interfaces based on feedstock alternatives
- Analysis of plant equipment layout
- Consideration of industrial/agricultural/food processing interfaces
- Consideration of process modifications resulting from interfacing options
- Consideration of time phasing of interfacing

Task III. Coupling-Matching Analysis

- Refining of connection-order analysis procedures
- Consideration of alternative production schemes
- Refinement of methodology to incorporate total systems integration criteria
- Preliminary analysis of constraints associated with matching of process interfaces

Task IV. Systems-Integration Analysis

- Preliminary analysis of optimization factors
- Preliminary analysis of candidate total-system combination
- Adaptation of cost-estimating methods
- Preliminary investigation of available computer-graphics techniques, equipment, and software
- Preliminary investigation of design flexibility requirements
- Preliminary analysis of time-phasing to achieve integration goals
- Preliminary considerations of safety requirements and procedures

Task VI. Regional Application Analysis

- Analysis of industrial site selection criteria
- Analysis of data on regional constraints and impacts

- Analysis of land availability and costs
- Characterization of availability of utilities
- Characterization of availability of labor
- Characterization of availability of transportation

Task VIII. Initiation of Utilization Plan

- Participation in AIChE/NSF Conference on Chemical Feedstock Alternatives held in Houston, Texas 10/2/77-10/5/77.
- Structured project Overview Committee and selected members as shown in Table I.
- Completed arrangements for first meeting of project Overview Committee meeting to be held at Georgia Tech on 10/28/77.
- Preliminary communications with federal, state, and local agencies involved in industrial planning and development.
- Preliminary planning for user workshop conference to be held at Georgia Tech in early 1978.

IV. Plans for Next Reporting Period

During the next six-month reporting period on this project, October 15, 1977 through April 14, 1978, the following efforts are planned:

- Continuation of Task I - Data-base Expansion.
- Completion of Task II - Development of Criteria for Total System Integration.
- Completion of Task III - Coupling-Matching Analysis.
- Continuation of Systems Integration Analysis on Task IV.

- Initiation of Task V - Tradeoff and Cost Benefit Analysis.
- Continuation of regional application analysis on Task VI.
- Continued implementation of utilization plan on Task VIII; complete planning, development and arrangements for user workshop conference on project results; conduct this conference at Georgia Tech in early 1978.

No significant problems have been encountered to date on this project, and originally anticipated progress and results are being achieved. No problems are anticipated for the next six months of activity on the project.

Yours very truly,

Jack M. Spurlock, Ph.D.
Henderson C. Ward, Ph.D.
Co-Principal Investigators

TABLE I. Members of Project Overview Committee

1. Mr. Richard L. Cowles (202) 566-4661
Department of Energy
Office of Conservation
Industrial Programs
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20461

2. Mr. Newt W. Hallman (312) 391-2511
Vice President of Engineering
Process Division
UOP, Inc.
20 UOP Plaza
Algonquin and Mt. Prospect Roads
Des Plaines, Illinois 60016

3. Mr. Vic Jelen (513) 684-4208
IERL-Ci
U. S. Environmental Protection Agency
5555 Ridge Avenue
Cincinnati, Ohio 45268

4. Mr. R. B. McBride (304) 747-4571
Energy Conservation Coordinator
Central Engineering Department
Chemicals & Plastics Division
Union Carbide Corporation
Technical Center, Building 2000, Room 4204
South Charleston, West Virginia 25303

5. Mr. Michael A. Potterf (202) 673-7845
Director, Division of Enterprise Development
Appalachian Regional Commission
1666 Connecticut Avenue, N.W.
Washington, D. C. 20235

6. Mr. John Pratt (713) 241-2242
Manager, New Site Development
1 Shell Plaza, Room 2259
P. O. Box 2463
Houston, Texas 77001

7. Mr. Seth Tuttle (NSF Sponsor) (202) 632-4110
National Science Foundation
AERRT
Room 1149
1800 G Street, N.W.
Washington, D.C. 20550

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ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

April 14, 1978

Grants Administrator
National Science Foundation
Washington, D.C. 20550

Attention: Ms. Mary Frances O'Connell

Reference: NSF Grant No. AER76-80993
(Georgia Tech Project No. B-0488-000)

Subject: Interim Progress Report No. 2
"Systems-Integration Requirements for the Synergistic
Co-Siting of Industrial Activities"

This report summarizes progress on the referenced grant project for the period October 15, 1977 through April 14, 1978.

I. Introduction

The purpose of this program is to apply advanced and comprehensive systems-integration methodology for the design of cost-effective, synergistically co-sited industrial activities. Synergistic co-siting involves the carefully planned grouping of industrial and/or agricultural activities in complexes that provide mutually beneficial utilization of energy, raw materials, co-products, land, plant wastes, and transportation facilities, as well as promote greater economical attractiveness of pollution-control measures, resource recovery, etc. Anticipated results of this study include practically achievable synergistic co-siting approaches to industrial-site planning, and to plant and process design, which offer the promise of some very effective and exciting possibilities for the simultaneous achievement of certain critical national and international goals such as resources (including energy) conservation, new energy sources, effective land use, improved food supply, improved environmental quality, and beneficial industrial development. These results, together with guidelines and recommendations for their practicable application, will be communicated appropriately to prospective users during the course of this study.

The rationale for our study involves a systematic search for, and evaluation of, industrial combinations which offer promise for grouping synergistically in some form of co-siting to satisfy total systems-integration criteria and accomplish program objectives. Our overall plan consists of a logical sequence of tasks designed to group functionally the investigative activities and facilitate the flow of the associated effort and results among these tasks. The tasks and their individual technical purposes are as follows:

Task I. Expansion of Data Base

Purpose: To compile adequate technical and economic information required as a basis for the extensive analyses that will be performed on subsequent tasks, including the addition of input-output information on more production commodities as an expanded reservoir of grouping candidates.

Task II. Development of Criteria for Total Systems Integration

Purpose: To establish guidelines for screening and selecting candidate process units, as required in the coupling-matching analysis, based on realistic benefit goals and systems-integration constraints.

Task III. Coupling-Matching Analysis

Purpose: To provide candidate industrial couplings for use in developing integrated, synergistically co-sited systems designs, based upon the guidelines formulated in Task II.

Task IV. Systems Integration Analysis

Purpose: To formulate and specify design features for fully-integrated co-siting complexes which meet the Task II guidelines.

Task V. Tradeoff and Cost-Benefit Analysis

Purpose: To evaluate realistically the practical advantages and disadvantages, institutional barriers and implementational potential for each of the candidate complexes identified and characterized on Task IV, as a basis for motivating user interest and initiative in pursuing demonstration development of such complexes.

Task VI. Regional Application Analysis

Purpose: To identify and characterize any features of regional (i.e., geographic, socio-economic, etc.) specificity which favor or exclude certain types of co-siting complexes or individual industrial activities, as a basis for categorizing general and limited applicability of the results and methodology of this program.

Task VII. Formulate Recommendations and Conclusions

Purpose: To develop and organize a set of useful guidelines for the application of the results and methodology produced on this program of research.

Task VIII. Initiate Utilization Plan

Purpose: To develop and implement a vigorous, effectual time-phased activity of identifying and communicating with user groups in an effort to (1) disseminate the concepts, evaluational results and significant new industrial-development tools produced on this program, and (2) maximize the benefit potential and usefulness of these program products in as large a user community as possible.

Task IX. Prepare Final Report

Purpose: To document the procedures, results, conclusions and recommendations of the program in an effective manner and appropriately time-phased to meet the reporting requirements of the National Science Foundation.

The interrelationships among these tasks are shown in Figure 1.

II. Project Schedule and Budget Status

The project effort is currently on schedule and operating within the budget plan. During this second reporting period, the schedule plan was revised somewhat from the plan presented in Interim Progress Report No. 1. These revisions, structured to provide a better flow and coupling of certain task efforts, consisted of the extensions of both Tasks II and III from nine to fifteen months. The revised schedule plan is shown in Figure 2.

Budget status through March, 1978 is as follows:

(1)	Total Expenditures to Date:	$ 77,672
(2)	Expenditures by Categories:	
	(a) Salaries of Principal Investigators and other Senior Personnel	$ 24,533
	(b) Other Direct Personal Services	$ 18,764
	(c) Materials and Supplies	$ 770
	(d) Travel (domestic only)	$ 908
	(e) Computer Services	$ 250
	(f) Overhead and Benefits	$ 32,447
(3)	Total Grant Funds Remaining:	$122,027

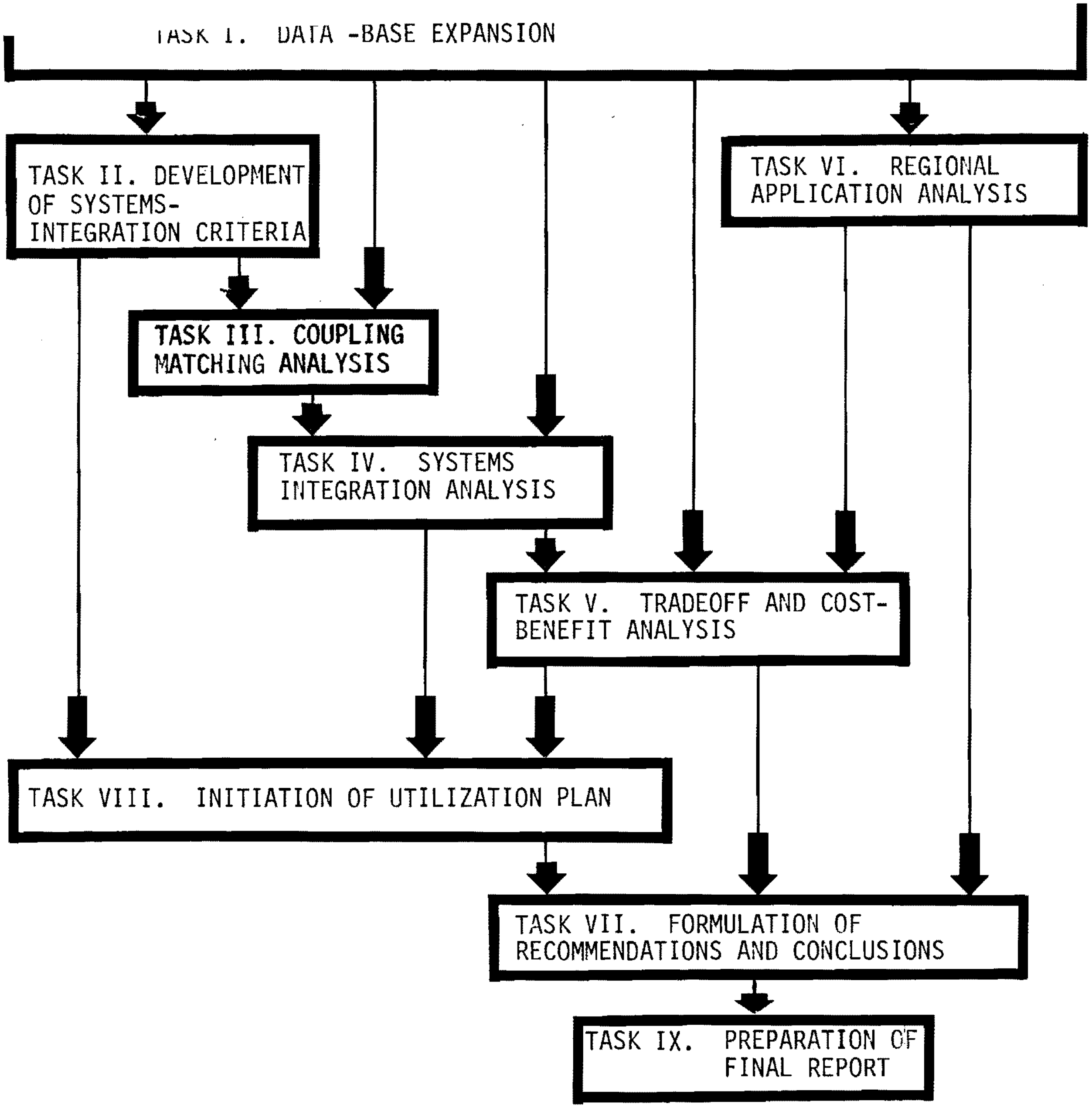

Figure 1. Task Interrelationships.

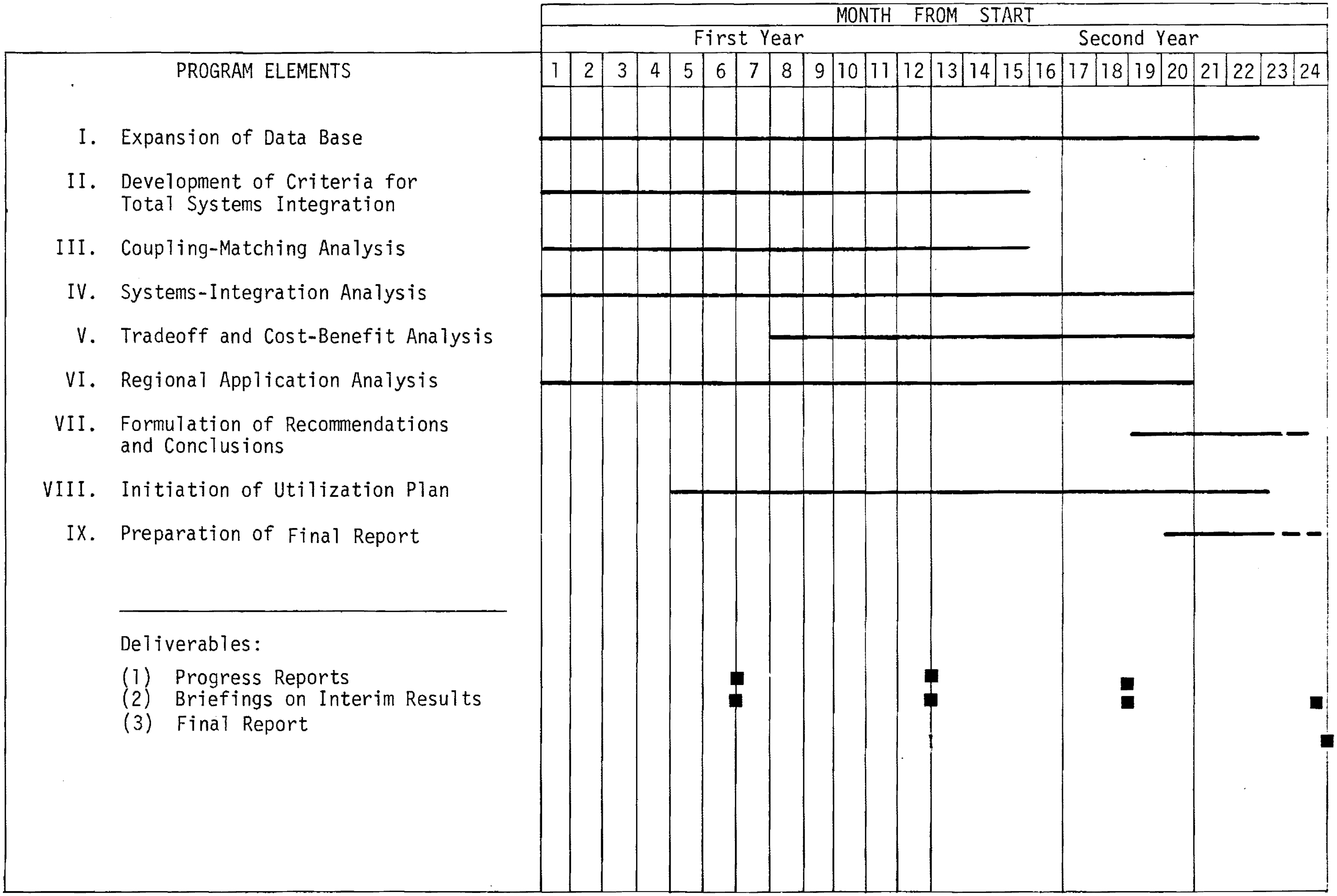

Figure 2. Program Schedule.

III. Technical Progress to Date

Technical progress during the second six-month reporting period of the project is summarized below, by tasks, for those task items that were scheduled for activity according to the schedule plan shown in Figure 2.

Overall Progress Summary

Effort was continued on Tasks I, II, III, IV, VI, and VIII, and initiated on Task V (each described in Section I of this report). All these efforts are on schedule and are providing the anticipated results to date. Tasks I, II, III, and IV are providing the information and basis required for the selection of several technically feasible candidate co-siting groupings; in addition, these tasks are producing a general methodology for such a preliminary selection process. Task V is providing information on practical advantages and disadvantages, as well as institutional barriers to industry's acceptance and implementation, of general co-siting approaches. This information will provide the basis for detailed cost-benefit and tradeoff analyses for specific candidate complexes later in this study. Task VI is providing information on local factors that affect the selection and use of land for various types of industrial sitings. These factors include costs; availability of utilities, labor force, and transportation; environmental constraints and community impact. Task VIII is providing extensive contacts and communication links with industry, federal, state, and local agencies, industrial developers and planners, and other potential user groups.

Capsule summaries of important elements of progress on each initiated task are presented below.

Task I. Expansion of Data Base

- Continued compilation of labor costs for industrial processes

- Continued compilation of land requirements for industrial processes
- Continued compilation and correlation of energy requirements of industrial processes
- Continued compilation of conversion factors and yields of industrial processes
- Completed procedure for alphabetizing data-base commodities
- Continued compilation of state-of-the-art pollution control equipment costs
- Continued compilation of safety requirements of industrial processes
- Continued compilation of waste products of industrial processes
- Continued compilation of pollutants of industrial processes
- Completed compilation of current pertinent EPA regulations for industrial processes; to be updated as required
- Compilation of unit cost data for industrial processes

Task II. Development of Criteria for Total Systems Integration

- Continued compilation and analysis of flow sheets to identify matching interfaces
- Continued investigation of interfaces based on pollutant utilization schemes
- Continued investigation of interfaces based on fuel and energy utilization schemes
- Identification and study of specific interfaces based on feed-stock alternatives
- Continued analysis of plant equipment layout
- Continued investigation of industrial/agricultural/food processing interfaces
- Continued investigation of process modifications resulting from interfacing options
- Continued investigation of time phasing of interfacing

Task III. Coupling-Matching Analysis

- Continued refinement of connection-order analysis procedures
- Modification of computer model to accommodate alternative production schemes as basis for optimization
- Continued refinement of methodology to incorporate total systems integration criteria
- Continued analysis of constraints associated with matching of process interfaces
- Development of improved matching and grouping format for computer model

Task IV. Systems-Integration Analysis

- Continued analysis of optimization factors
- Selection and preliminary analysis of specific total-system combinations based on feedstock alternatives, including coal (hard and lignite), fuel oil, naphtha, municipal waste, and biomass
- Continued adaptation of cost-estimating methods
- Completed compilation of information on available computer-graphics techniques, equipment, and software
- Continued investigation of design flexibility requirements
- Continued analysis of time-phasing to achieve integration goals
- Continued compilation of data on safety requirements, procedures, and regulations for industrial processes

Task V. Tradeoff and Cost-Benefit Analysis

- Development of preliminary cost-benefit model for candidate co-sited complexes
- Consideration of important tradeoff factors, based on discussions with Overview Committee, for integration and siting of complexes

Task VI. Regional Application Analysis

- Continued analysis of industrial site selection criteria
- Continued analysis of data on regional constraints and impacts
- Continued analysis of land availability and costs
- Continued characterization of availability of utilities
- Continued characterization of availability of labor
- Continued characterization of availability of transportation
- Incorporation of industry and federal-agency viewpoints based on Overview Committee's inputs

Task VIII. Initiation of Utilization Plan

- First meeting of project Overview Committee was held at Georgia Tech on 10/28/77 (minutes, including agenda, are attached)
- Ten-minute presentation on Georgia Tech Radio Station WREK on Synergistic Co-Siting by Dr. Spurlock on 11/15/77
- Paper by project team, entitled "Identification and Analysis of Potential Chemical Manufacturing Complexes," published in Journal of Regional Science, Volume 17, Number 3, December, 1977 (reprint attached)
- Paper entitled "Energy Conservation in Industry through Synergistic Co-Siting," presented by Dr. Spurlock at the Energy Colloquium held at the University of Georgia on 2/28/78 (copy of paper attached)
- Continued communications with federal, state, and local agencies involved in industrial planning and development
- Continued planning for user workshop conference to be held at Georgia Tech at a date to be coordinated with regional planners

IV. Plans for Next Reporting Period

During the next six-month reporting period on this project, April 15, 1978 through October 14, 1978, the following efforts are planned:

- Continuation of Task I - Data-base Expansion
- Completion of Task II - Development of Criteria for Total System Integration
- Completion of Task III - Coupling-Matching Analysis
- Continuation of Systems Integration Analysis on Task IV
- Continuation of Task V - Tradeoff and Cost-Benefit Analysis
- Continuation of regional application analysis on Task VI
- Continued implementation of utilization plan on Task VIII; plan and conduct second meeting of Project Overview Committee

No significant problems have been encountered to date on this project, and originally anticipated progress and results are being achieved. No problems are anticipated for the next six months of activity on the project.

Yours very truly,

Jack M. Spurlock, Ph.D.
Henderson C. Ward, Ph.D.
Co-Principal Investigators

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

November 18, 1977

MEMORANDUM

TO: NSF Synergistic Co-Siting Project Overview Committee

FROM: Jack Spurlock and Henderson Ward

SUBJECT: Minutes of First Overview Committee Meeting on 10/28/77

The first meeting of the Overview Committee for the NSF sponsored grant project "Systems-Integration Requirements for the Synergistic Co-siting of Industrial Activities" (Georgia Tech Project No. B-0488-000) was held on 10/28/77 in Room 303, Baker Building Auditorium, Georgia Tech Engineering Experiment Station. Attendees were:

Mr. Richard L. Cowles
Ms. Anita Fey
Mr. Newt W. Hallman
Mr. Vic Jelen
Mr. R. B. McBride
Mr. John Pratt
Dr. Jude T. Sommerfeld
Dr. Jack M. Spurlock
Mr. Seth Tuttle
Dr. Henderson C. Ward

The meeting followed closely the Agenda and Work Plan which was mailed to committee members prior to the meeting. A copy of this Agenda and Work Plan together with a current roster of Committee members is attached.

At the beginning of the meeting, participants were provided with a notebook containing background information on the project.

A summary of the essential comments, ideas, and suggestions exchanged during the morning session is presented below:

Morning (9-11:45)

Welcome, introductions, major features and potential significance of synergistic co-siting (Spurlock & Ward)

NSF perspective as sponsoring organization (Tuttle)

Project background, objectives, and scope (Ward, Spurlock and Sommerfeld)

Key comments by committee members in response to above presentations:

- A major rationale for co-siting is company survivability (e.g., recent Ethyl Corporation ad to attract co-siting partners).
- Considering the costs of detailed economic estimates for industrial ventures, the most realistic approach on this project is to use approximate techniques and attempt to establish maximum and minimum probable costs.
- Advisable to seek return on investment (ROI) criteria from user industry.
- Co-siting methodology based only on chemical plants of little interest or value to large chemical companies but could be of considerable value to the smaller chemical companies producing a limited number of products.
- Co-siting methodology based on mix of chemical and non-chemical activities (such as agricultural, food, forestry) could be of value to the large chemical companies.
- Great need exists for development of schemes to utilize low temperature energy (less than 250^{o}F) presently abundantly available.
- Incentives needed to promote industry acceptance of co-siting.
- Refineries are continually updating both processes and equipment to meet competitive pressures.

Noon (11:45-1:30)

The Committee had lunch together in the Georgia Tech Student Union and afterwards toured some of the current Georgia Tech Energy and Environmental Research Activities. These included the newly completed 400 kw (thermal) solar power-generation research facility and the pilot plant for the pyrolytic conversion of agricultural wastes into industrial fuels.

Afternoon (1:30-4:15)

During the afternoon Workshop Session, attention was focused on three categories. The essential comments, ideas, and suggestions exchanged during this session are summarized below by categories.

Category I -- Feedstocks and Fuel Alternatives; Energy Consumption and Conservation

- Tar sands a possible feedstock source. Less potential trouble than shale oil. Large sources available in South America and Canada. Great Canadian Oil Sands (GCOS) in operation. Now competitive, but only because it was built with 1960's money at about $350 million.
- Shale-oil technology essentially available; awaiting economics.
- Coal probably least attractive feedstock alternative for the near future.
- Coal will be used principally as boiler fuel. Stationary use; not attractive for transport.
- Limited interest in hydrogen use. Viewed as just a reactive chemical.

Category II -- Land Use, Site Selection and Environmental Constraints

- Environmental constraints vary from state to state and from region to region.
- A key site-selection factor is to provide most economic route from raw material source to market.
- Many companies have had bitter experiences in site selection and purchase-Shell in Delaware, Dow in California, etc.

- Low temperature applications abound. Need key matching criteria development.
- Industry usually buys land in sections (1 section = 1 square mile = 640 acres). Typical minimum is 1 section.
- Industry usually purchases about 2 to 3 times minimum land required.
- Industry "rules of thumb" --

  on-site: $20 million of equipment/acre
  off-site: $ 1 million of facilities/acre.
- Maximum realistic construction labor force is approximately 2,000 at any time.
- About all that can be built at one site at one time, based on labor force saturation of the site, is equivalent to one world-scale ethylene plant; other associated units would have to await completion of this major unit.
- Houston is considered to have the best labor pool of skilled refinery construction workers.
- East coast sites are desirable but are practically unavailable due to various restrictions. Therefore, tradeoffs favor southern and south-western sites.
- Typical distribution of investment in increased refinery capability is 85% add-on to existing facilities and 15% for new ("green fields") construction.
- Site selection should avoid scenic rivers and parks (existing and planned).

Category III -- Project Methodology

- Better source of current plant and equipment costs is construction firms and vendors rather than detailed flow sheet analysis.
- In considering regional impacts, it is best to favor sites where the industry is needed and wanted and adequate construction labor is available. For example, Houston and Corpus Christi are good; Wood River,(Illinois),New Jersey, New York and St. Louis are bad.
- Chemical Week publishes an annual rating of industrial sites.
- Site-selection analysis should seek to minimize overall transportation costs (e.g., avoid backtracking).

- State and local taxes are not major considerations in site selection but can be a "tie breaker,"

- Water availability and amount is a most important consideration if heat rejection requirements are large. For example, shortages of water where oil shale is abundant pose a major problem.

- Stable political environments are important regional considerations to avoid unfavorable changes in terms and conditions of plant sitings.

- Avoid unethical dealings in site acquisition.

- It is possible to completely enclose ("can") a plant environmentally for a price. Examples are refineries in Los Angeles basin and Scandinavian countries.

The meeting was adjourned at 4:15 PM, slightly ahead of schedule, to allow a number of the Committee members to meet plane schedules. It was announced that the next meeting of this Committee is tentatively scheduled for late spring or early summer of 1978.

FOOTNOTES:

A. Materials received from Committee members during meeting

(Cowles) 1. Copy of draft final report on cogeneration study by Research Planning Associates, Inc. (sponsored by Federal Energy Administration).

(Hallman) 1. James, R.B., Fickel, R.G., and Sepiol, S.J., "A Realistic Approach to Energy Conservation," Paper presented at the UOP Technology Conference, October, 1977.

2. Collection of news clippings on industrial energy conservation initiatives (principally cogeneration).

B. Material to be forwarded by Committee members

(Cowles) * 1. Copy of report: Barnes, R.W., "The Potential Industrial Market for Process Heat from Nuclear Reactors," Dow Chemical Company (sponsored by ERDA-Oak Ridge), January 1976.

* 2. MIUS Bibliography, NBS Special Publication 489, (U.S. Dept. of Commerce & HUD).

* 3. "Energy Conservaton and Environment Publications," Federal Energy Admin. conservation publications bibiliography, July 1977.

* 4. Copy of report: Gyftopoulos, E.P., et al, "Potential for Effective Use of Fuel in Industry," Thermo Electron Corp., for the Ford Foundation, April 1974.

(McBride) * 1. Shiroka, K. and Umeda, T.,"Energy Conservation in Petroleum Refineries - Current Status and Future Trends," Chemical Economy and Engineering Review, 18-25, November 1976.

* 2. Union Carbide videotape, "Cajun Country".

(Jelen) 1. Kanawha Valley Study, Corps of Engineers -- Ohio River Division, Cincinnati, Ohio. Study deals with land use and groupings.

* -Received by date of preparation of these minutes.

AGENDA AND WORK PLAN FOR

FIRST MEETING OF OVERVIEW COMMITTEE

NSF SYNERGISTIC CO-SITING PROJECT

303 Baker Building (Auditorium)
Georgia Tech Engineering Experiment Station

October 28, 1977

9:00 - 9:15	Welcome and Introductions
9:15 - 9:45	Major Features and Potential Significance of Synergistic Co-Siting
9:45 - 10:00	NSF Perspective as the Sponsoring Organization (Mr. Seth Tuttle)
10:00 - 10:45	Project Background, Objectives, and Scope
10:45 - 11:45	General Discussions of Trade-off Factors such as:

- Ownership (Management Structures for Co-siting Ventures)
- Operational Reliability Interdependency among Coupled Units
- Effect on Protection of Proprietary Processes
- Requirements for and Availability of Adequate Land for All Units
- Proximity to Markets, Raw Material and Other Resources for All Units
- Regional and Community Impact (On and by the Co-sited Complex)

11:45 - 12:45	Lunch
12:45 - 1:30	Tour of Georgia Tech Energy and Environmental Research Activities
1:30 - 4:45	Workshop Session -- This will consist of an informal exchange of ideas, information and intuitions on several topics of importance to the project. Solutions, or approaches to solutions, to the problems listed on the attached sheet will be discussed.
4:45 - 5:00	Summary and Assessment of Workshop Results
5:00	Adjournment

Key Problem Areas as Topics for Workshop Session

Category I -- Feedstock and Fuel Alternatives; Energy Consumption and Conservation:

- What are the current and future problems and options?
- What are the appropriate roles for various synergistic co-siting modes in contributing solutions and improving economic attractiveness of options?

Category II-- Land Use, Site Selection and Environmental Constraints:

- What data are available on land requirements for various chemical processes?
- What data are available on emission and effluent control requirements for various chemical processes?
- In its current and future site planning, how is industry responding to environmental control pressures (in the U.S. and abroad)?
- How can co-siting applications improve site selection, planning and approval processes for industry and regional planners?
- What are the key factors that must be considered in applying co-siting concepts to land-use planning?

Category III- General Discussion on Project Methodology, Including:

- Cost estimating techniques
- Flowsheet availability
- Process matching criteria
- Process coupling interfaces
- Graphical-design computer techniques
- Data-base requirements

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ENERGY CONSERVATION IN INDUSTRY THROUGH SYNERGISTIC CO-SITING

J. M. Spurlock and H. C. Ward

Georgia Institute of Technology

INTRODUCTION

A team of chemical engineers and industrial economists at Georgia Tech became deeply involved with the issue of industrial energy conservation, beginning in 1974 with a research contract sponsored by the Federal Energy Administration (1). The objective of that study was to develop computerized procedures for an anticipated federal program of mandatory reporting of energy conservation initiatives by energy-intensive industrial operations. The chemical and metallurgical manufacturing industries were among the most intensive users of energy. The study required very close interaction both with a regulatory agency and industry, and especially the trade associations that tend to represent the major, aggregated voice of these industries to the Federal Government.

The research team became very familiar with industry's attitude concerning voluntary or cooperative compliance with various federal regulations and guidelines which industry considers to be economically oppressive. In general, these attitudes are antagonistic toward mandated or recommended changes from conventional methodology to alternatives unless there are clearly defined economic incentives. Thus, a change to alternative processing options, only to satisfy national conservation goals, would be regarded as poor economics if this shift would adversely affect profits.

In the case of energy conservation, some initiatives such as added insulation on pipes, reuse of waste heat and less wasteful process cycles often are economically beneficial and convenient to implement as well as energy conserving; therefore, industry has been willing to accept and employ these measures. However, certain significant modifications in process technology, such as shifting to chemical feedstocks derived from more abundant sources, which might provide major energy independence benefits for the nation, have not received serious attention by most of the chemical process industry. For example, it was very apparent to participants in a recent industry-government conference on chemical feedstocks alternatives that industry, by and large, is not willing to spend much effort in looking at alternatives (such as coal, shale oil, waste and biomass) until the availability situation for natural gas and petroleum is virtually critical (2). The prevailing attitude is "let others use that stuff for fuel and reserve the gas and oil for our feedstocks."

In another example case, it is well known that environmental conservation measures are barely tolerable to industry. At least the increasing cost of fuel adds some economic incentives to energy conservation; but environmental control measures are generally regarded by industry as a dead burden on profits. There are easily identifiable instances where certain industrial spokesmen have promoted an issue of energy conservation versus environmental protection; i.e., an either-or view of the options. It is quite certain that the supporters of this view are hoping that energy will win in the debate.

In perspective, these attitudes typically have resulted in completely reactive and largely involuntary actions that principally consist of "quick-fixes." The large inertia associated with long-range planning also contributes very significantly to the onset of these shortsighted responses. Then the inefficiencies of a strictly reactive mode of response compound the problem and worsen economic incentives even further. In addition, a bad economical result is assumed in advance of implementing these forced changes and the prediction becomes almost self-fulfilling. Thus, based on all of these counterproductive influences, poor cost-effectiveness of many of the conservation measures to date is not surprising.

CONCEPT OF SYNERGISTIC CO-SITING

There appears to be a major need for a systematic approach to conservation in industry that could provide longer-range benefits from carefully planned combinations and integration of processing as well as operational changes based on innovative systems designs. In 1975 the Georgia Tech team began a program of intensive study to identify concepts of this type. This study led to the development of a concept and methodology for coupling several industrial activities or processes, through the integration of their common interfaces, to achieve synergism and spread the cost and benefit of conservation measures. We have termed this broad concept as "Synergistic Co-siting."

By our definition of Synergistic Co-siting, this concept involves the carefully planned grouping of industrial activities, including agricultural operations, in complexes to simultaneously promote:

1. Mutually beneficial utilization of all resources, including energy, raw materials, co-products, plant wastes and effluents, land and transportation facilities; and

2. Greater economical attractiveness of innovative approaches such that industry will have new incentives for the conservation of resources in support of national needs.

Approaches to industrial plant and process design, as well as site planning, based on this methodology, offer the promise of some very effective and exciting possibilities for the simultaneous achievement of certain critical national goals and industrial profitability requirements. Certainly, one of the major objectives of this study is to at least attenuate the adversary relationship that has developed between these two very worthy ideals. The pioneering phase of this research was funded by the Appalachian Regional Commission, through the State of Georgia, as a preliminary feasibility investigation (3,4). The National Science Foundation's Directorate for Applied

Science and Research Applications is sponsoring the current phase of study which includes a detailed systems analysis and methodology development.

Possibilities for matching or mating industrial operations in a synergistic manner are defined in terms of process interfaces which they might be able to share. Some examples of these interfaces are shown in Table 1. Candidate industrial groupings, or complexes, are then selected through a computerized matching analysis that seeks to maximize the number of shared interfaces among component processes in the groupings. The extent of benefit potential is directly proportional to the amount of interface sharing that can be accomplished by the grouping design. A hypothetical example of a synergistically co-sited complex of industrial and agricultural activities is shown in Figure 1. Examples of national benefits that are anticipated from the application of fully integrated synergistic co-siting include:

- Energy conservation.
- Development of new feedstock options.
- Economical recovery of resources and waste.
- Improved methods and incentive for pollution control.
- Reduction of site-approval time for new plants.
- Improved product mix.
- Improved stability of labor pools and job opportunities.
- Optimum use of land.
- Optimum use of transportation facilities.
- Improved profitability and productivity.

To make this analysis complete and realistic, attention is also being given to potential disadvantages or trade-off considerations. Possibilities include: (1) interdependency among the component industrial units and effects on operational reliability or carryover fire and explosion vulnerability; (2) presence of larger storage pools of hazardous chemicals; (3) impact on the protection of proprietary processes; (4) regional and community impact of new, larger industrial complexes; and (5) the question of the availability of suitable land sites to satisfy the needs of all units in the complex. However, in general, these trade-off factors are essentially the same as those that are involved in conventional multi-process complexes and joint ventures that are common practice today.

DEVELOPMENT OF METHODOLOGY

The Georgia Tech research team is currently developing computerized procedures for the selection, screening and evaluation of candidate synergistic complexes. In addition, the methodology includes a detailed evaluation of the practical effects of industrial co-siting and the cost-effectiveness of its applications on any reasonable scale. The specific components of the methodology are:

- Data base for a large number of industrial processes, consisting of a characterization and quantification of their major input and output interfaces (see Table 2).

Table 1. Typical Process-Matching Interfaces.

- Product of Process A is a Raw Material of Process B.
- Waste Product (effluent) of Process A is a Raw Material of Process B.
- Waste Energy of Process A Satisfies an Energy Requirement of Process B.
- Waste from Process A Can Become a Product or Raw Material if Used as an Input to Waste-Conversion Process B.
- Intermediate or By-Product of Process A is a Raw Material of Process B.
- Common Fuel or Feedstock Serves as Input to Both Process A and Process B.
- Product or By-Product from Process A Serves as Raw Material for Process B After First Being Subjected to Process C.
- Waste and/or Effluents from Processes A and B Provide Benefits When Commonly Routed to Waste-Treatment Process C.

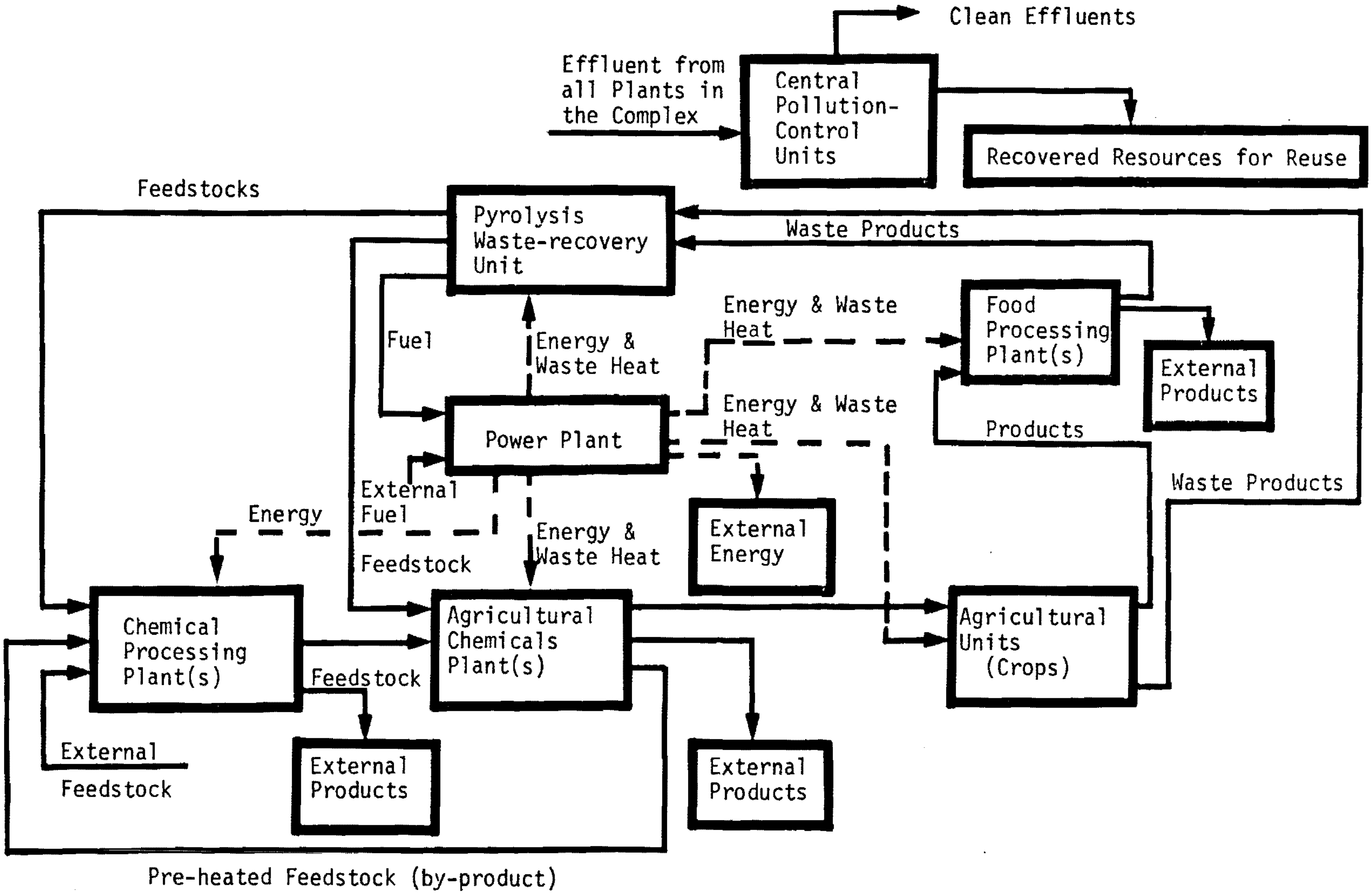

Figure 1. HYPOTHETICAL EXAMPLE OF A SYNERGISTICALLY CO-SITED COMPLEX.

Table 2

DATA-BASE ENTRY FORMAT FOR INDUSTRIAL PROCESSES

PROCESS NAME__________________ ACCESS/I.D. CODE NO.__________

CARD NO.__________

TOTAL NO. OF CARDS__________

I. PRODUCT/RAW-MATERIAL INTERFACES:

A. PRINCIPAL PRODUCT (CODE) __________ ( )

B. BY-PRODUCT OR CO-PRODUCTS (CODES) __________ ( ) __________ ( )

__________ ( ) __________ ( ) __________ ( )

C. RAW MATERIAL, FEEDSTOCK & OTHER INPUT-MATERIAL REQUIREMENTS (CODES)

__________ ( ) __________ ( ) __________ ( )

__________ ( ) __________ ( ) __________ ( )

__________ ( ) __________ ( ) __________ ( )

II. WASTES, EFFLUENTS AND EMISSIONS OUTPUT INTERFACES (CODES):

__________ ( ) __________ ( ) __________ ( )

__________ ( ) __________ ( ) __________ ( )

__________ ( ) __________ ( ) __________ ( )

III. ENERGY-USE INTERFACES:

A. INPUT REQUIREMENTS (CODES):

__________ ( ) __________ ( ) __________ ( )

__________ ( ) __________ ( ) __________ ( )

__________ ( ) __________ ( ) __________ ( )

B. OUTPUT CHARACTERISTICS (CODES):

__________ ( ) __________ ( ) __________ ( )

__________ ( ) __________ ( ) __________ ( )

__________ ( ) __________ ( ) __________ ( )

- Matching and grouping analysis which selects pairs and then progressively larger synergistic groupings to eventually structure a candidate complex.

- Systems-integration analysis to complete the complex, maximize the synergism at the coupled interfaces and evaluate overall technical feasibility.

- Trade-off and economic analyses which compare the candidate synergistic co-siting complexes with conventional manufacturing and siting practices in terms of cost-risk-benefit evaluations.

- Regional impact analysis, including a policy assessment, to maximize incentives for acceptability and implementation of candidate complexes.

Methodology development is continuing and several very interesting candidate complexes are presently being evaluated in depth. In the earlier phase of this research, sponsored by the Appalachian Regional Commission, emphasis was placed on complexes that were based upon raw materials which are abundant in the Appalachian Region. For example, one candidate complex centered on the production of aluminum from kaolin, which had commercial significance in Georgia. In the current phase of this program, one of the more promising candidate complexes is centered on the production and highly integrated use of synthesis gas from more abundant raw materials such as coal, municipal waste and biomass, as shown schematically in Figure 2. The principal benefits that are expected from this grouping derive from (1) the potential use of a wide variety of raw materials, including mixtures, to provide more extensive flexibility in choosing feed sources, based on availability; (2) a very attractive product mix, including several high-demand commodities such as ammonia and methanol; and (3) greatly reduced impact on the environment through the conversion of virtually all the by-products, such as hydrogen sulfide and carbon dioxide, into useful, marketable commodities. It is anticipated that the longer-ranged economic credits associated with these aspects of a highly integrated industrial system can offset any marginal short-ranged cost advantages of conventional processing methods to the extent that industrial interest will be attracted.

The major goal is sufficient incentives to trigger a more rapid shift by industry to alternative feedstocks. Currently, natural gas and petroleum are the feedstock sources used in the production of ammonia and methanol. Particularly in the case of natural gas, industrial use is extremely large, representing nearly half the demand for natural gas in the United States in 1976 (5). Therefore, any economically attractive alternatives to natural gas for industrial uses must be granted serious attention in an effort to relieve the critical availability problem that exists for this non-renewable energy resource.

Other candidate complexes, oriented toward the solution of conservation problems, will be investigated in detail on this program of study. From preliminary analyses conducted to date by our team, it appears that the application of synergistic co-siting can enhance the economic attractiveness of conservation measures such as solar energy use in industrial processing, waste recovery and biomass use as an energy source.

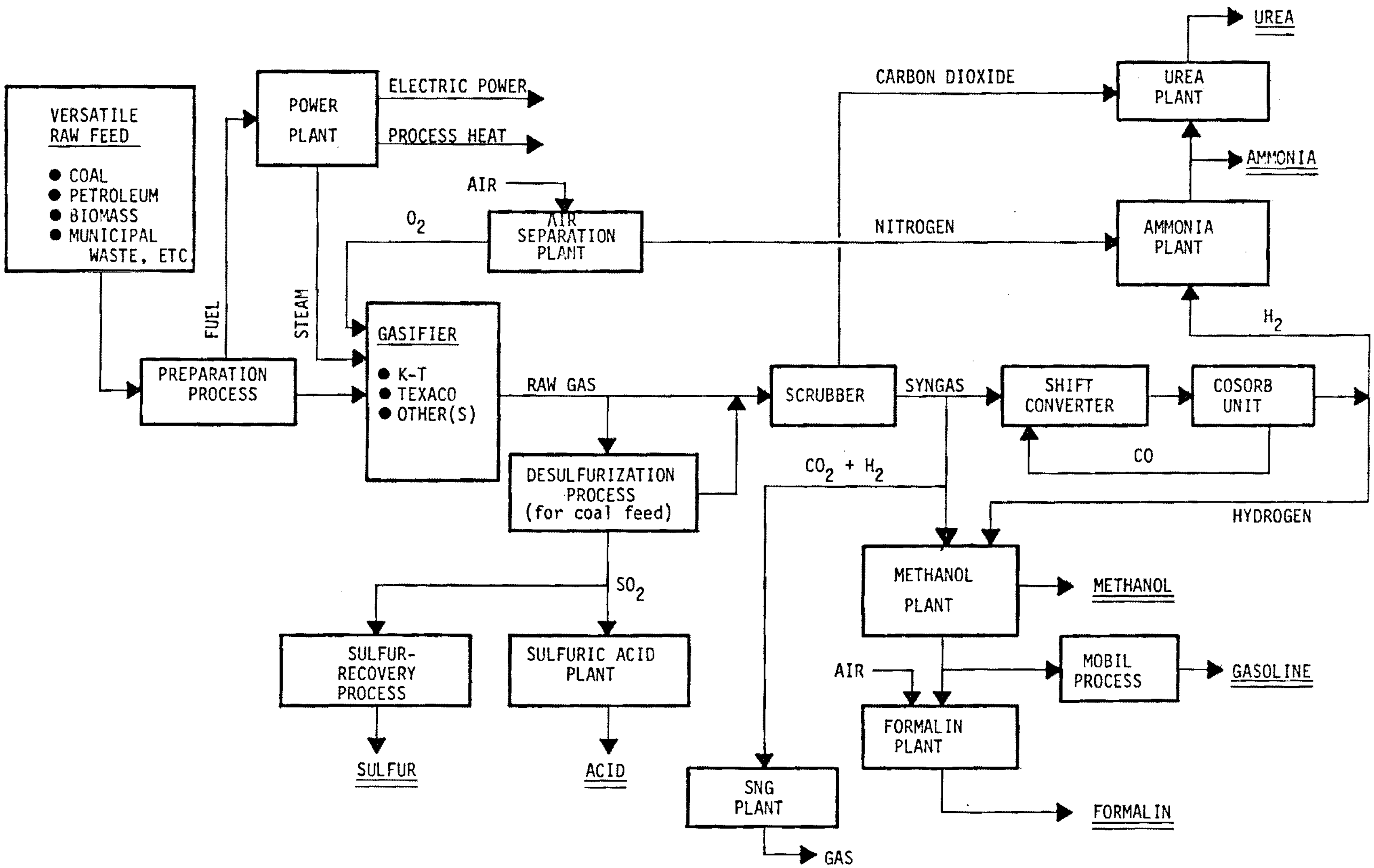

Figure 2. FLOWSHEET FOR A CANDIDATE COMPLEX BASED ON SYNTHESIS-GAS FEEDSTOCK FROM COAL, WASTE AND BIOMASS.

UTILIZATION PLAN

Innovative concepts and methodology that often result from research studies, particularly those performed by academic research teams on government-sponsored grants and contracts, frequently do not find widespread acceptance and implementation into practice by industry. One of the major reasons for this is inadequate communication with potential users of the innovative technology. This shortcoming is promoted not only by poor dissemination of final results at the end of a study, but also by a failure to incorporate the users' viewpoints into the study during the course of the research. The latter tendency can preclude the consideration of, and compensation for, real-world constraints that might well prove to be the principal barriers to acceptance of the study's results. This is a common source of criticism from industrial representatives concerning the research results produced by non-industrial investigators.

In an effort to circumvent these communication problems, the Georgia Tech team has included a multifaceted utilization plan as a task component of this study. For example, an overview committee has been organized, consisting of highly qualified representatives of industry as well as government agencies, to provide the research team with valuable feedback. Workshop meetings are held at least twice per year to review current study results, approaches and plans for subsequent phases of work. These workshops are contributing importantly to the orientation of the project's work plan. The committee has no control authority over the research, and no attempt is made to derive concensus recommendations during the workshops. It functions strictly as a source of practical experience and counsel, and the spirit of cooperation has been outstanding. We highly recommend this approach in studies such as this in which working technical compromises are being sought to solve important national problems and resolve conflicts between governmental policies and industrial motives.

REFERENCES

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2. "Tomorrow's Feedstocks: From Where Will They Come?" 1977. Chemical Engineering Progress 73 (12): 23-25.

3. Spurlock, J.M.; Ward, H.C.; Sommerfeld, J.T.; Husted, J.E.; and Sondhi, D.K. 1976. "Study to Investigate Potential Benefits from Synergistic Co-siting of Industrial Activities." Final report for Appalachian Regional Commission on Grant No. GA-4234-75-1-302-0509.

4. Sommerfeld, J.T.; Sondhi, D.K.; Spurlock, J.M.; and Ward, H.C. 1977. "Identification and Analysis of Potential Chemical Manufacturing Complexes." Journal of Regional Science 17(3): 421-430.

5. Legassie, R.W.A.; and Ordway, F.I. 1977. "A Quick Look at the National Energy Plan." Astronautics and Aeronautics: 28-35.

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IDENTIFICATION AND ANALYSIS OF POTENTIAL CHEMICAL MANUFACTURING COMPLEXES*

Jude T. Sommerfeld, Dalip K. Sondhi, Jack M. Spurlock and Henderson C. Ward†

This article describes methodology which has been developed to identify and analyze potential chemical manufacturing complexes. Isard and coworkers [7, 8, 9] pioneered the concept of industrial complex analysis, beginning with a design in the nineteen fifties of a petrochemical complex for Puerto Rico (Isard, Schooler, and Vietorisz [7]). Recently, Isard extended his methodology to include environmental management activities, with specific reference to a proposed coal powerplant complex in New York State [10].

Various government agencies have published a number of reports and papers concerning investigations of industrial and agroindustrial complexes centered around nuclear reactors. These complexes are typically designated as "nuplexes," an acronym derived from nuclear complexes. Czamanski [4] has focused attention on clustering of industrial activities and developing identification and analysis methods based on the use of input-output tables. Conway [2] has studied the grouping of related activities around waste-treatment plants and has designated such groupings as "decoplexes," derived from development/ecology/complexes. Integrated "coldplexes" are the subject of another recent article (Witwer, Ushiba, and Semrau [17]).

Indeed, at the present time there are many economically sound and well-integrated industrial complexes in operation in this country and abroad. Yet, while the existence of these operating complexes and the results of current and previous studies provide credibility and needed background for co-siting concepts, co-siting methodology is still in a state of development. The methodology described below has been developed for use in the context of manufacture of chemical commodities, but is readily extendable to other industrial activities.

1. DATA BASE DEVELOPMENT

For purposes of demonstrating this methodology in a chemical manufacturing environment, a data base consisting of process flowsheet and economic data on

* The work described herein was performed under a grant from the Appalachian Regional Commission to the Engineering Experiment Station of the Georgia Institute of Technology.

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Date received: February, 1977.

The nth reachability matrix is thus given as $R_n = \sum_{i=1}^{n} A_i$. This procedure is continued until there is no change between successive reachability matrices. The last reachability matrix is known as the infinite reachability matrix (R_∞). The transpose of this infinite reachability matrix is then formed, and finally the intersection of these latter two matrices is determined; that is, $W = R_\infty \cap R_\infty^T$. The square submatrices of the intersection matrix W with true values then locate all of the recycle loops in the process.

3. APPLICATION TO CHEMICALS PRODUCTION

In this work, a first Boolean matrix is constructed from the relationships between inputs and outputs for the chemical commodities (e.g., raw materials, intermediate products, final products and by-products). A true value for a_{ij} denotes that commodity i is directly consumed in the production of commodity j, or that commodity i is formed as a by-product in the production of commodity j. Following the suggestion of Roepke *et al.* [15], whereby the total interchange between industries (chemical commodities in the present case) in an aggregated transactions matrix is shown regardless of their input or output roles, a first adjacency matrix (A_1) is formed as the sum of the first Boolean matrix and its transpose. Higher-order adjacency matrices are then constructed as described above. In these Boolean matrix multiplications, the algorithm suggested by Lowe [12] to reduce CPU time is employed.

Successive reachability matrices are also computed as described above. New true entries in a reachability matrix of a given order (n), and which were not present in the reachability matrix of one less order, are extracted and examined. These new entries represent nth order connections between the chemical commodities and suggest various possible coupling arrangements in a co-sited complex.

4. EXAMPLE OF IDENTIFICATION OF CO-SITING CANDIDATES

As a rather simple example of this procedure, consider the following sequence of chemical reactions used to manufacture several industrial chemicals:

$$C_2H_4 + \tfrac{1}{2}\,O_2 \rightarrow C_2H_4O \tag{2}$$

$$C_2H_4O + NH_3 \rightarrow NH_2C_2H_4OH \tag{3}$$

$$C_2H_4 + \tfrac{1}{2}\,O_2 \rightarrow CH_3CHO \tag{4}$$

Let these chemical compounds be numbered and assigned aliases in the following fashion:

Number	Name	Formula	Alias
1	Ethylene	C_2H_4	C_2H_4
2	Oxygen	O_2	O_2
3	Ethylene Oxide	C_2H_4O	EO
4	Ammonia	NH_3	NH_3
5	Monoethanolamine	$NH_2C_2H_4OH$	MEA
6	Acetaldehyde	CH_3CHO	AA

Forming the third reachability matrix as $R_3 = A_3 + R_2$, we find that all of the entries of R_3, except for r_{46} and r_{64}, are true. Comparing this result with R_2, we observe the following new connections corresponding to third-order connections between these chemical compounds: ethylene and NH_3, oxygen and NH_3, and MEA and AA. The latter third-order connection is through EO, then through either C_2H_4 or oxygen, and then to acetaldehyde. If one were to form A_4 and then $R_4 = A_4 + R_3$, the entries of this fourth reachability matrix would all be true, disclosing a fourth-order connection between NH_3 and AA. For this reaction system, this latter connection would be the last and highest-order new connection.

In practice, a user of this algorithm would supply the names of chemical commodities of interest and which were stored in the data base. These commodities could be raw materials such as coal, brine and naphtha, intermediate products such as ethylene, phenol and cyclohexane, or final products such as polyethylene and ethylene glycol (antifreeze). One thus has the capability to search for both forward and backward integration possibilities in a co-siting environment. A user would also typically supply a finite limit on the number of reachability matrices to be constructed. As output, he would obtain all unique connections and their orders between his chemical commodities of interest and the remainder of the commodities stored in the data base.

5. SPARSE-MATRIX REDUCTION

Having identified potential co-siting candidates according to the procedure described above, it remains to determine the technical configuration of and economic benefits resulting from co-siting of the indicated activities. At this point, information stored in the computerized data base is again employed. Having decided upon merchant production rates for the various desired products, the total production rates (activities) for all of the associated chemical commodities must be determined. This is essentially a material balance problem, employing the coefficients establishing the input-output relationships between the various chemical commodities. The resulting coefficient matrix is sparse (population density generally less than 10 percent), and advantage may be taken of recently developed procedures for the reduction of sparse matrices.

The sparse matrix reduction method employed in this work is based upon the algorithm proposed by Bending and Hutchison [1]. This method was originally developed to calculate steady-state flows in networks of pipes and pumps handling an incompressible fluid. In essence, the steps required for triangularization of the sparse matrix are delineated and memorized in an operator string of integers corresponding to element numbers. The complete matrix is never core-resident; rather, the matrix is represented by three vectors corresponding to row locations, column locations and coefficient values for only the nonzero entries. After triangularization, a second operator string is constructed and memorized for the back-substitution steps to develop the solution vector. This method is extremely efficient in the analysis of parametric cases corresponding to various coupling-matching tests, wherein the matrix structure remains fixed, but the matrix coefficients are free to vary from case to case. The two operator strings need to be constructed only for the first case. These strings are then used to drive the solution process in this and all succeeding cases. Actual inversion of the matrix is never

$$
\begin{vmatrix}
a_1 & & a_8 & & & a_{12} & \\
& a_2 & a_9 & & & a_{13} & \\
& & a_3 & & a_{10} & & \\
& & & a_4 & a_{11} & & \\
& & & & a_5 & & \\
& & & & & a_6 & \\
& & a_{14} & & & & a_7
\end{vmatrix}
\cdot
\begin{vmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \\ x_7 \end{vmatrix}
=
\begin{vmatrix} a_{15} \\ a_{16} \\ a_{17} \\ a_{18} \\ a_{19} \\ a_{20} \\ a_{21} \end{vmatrix}
\tag{10}
$$

where the subscripts of the coefficients pertain to their location in a vector of such elements, and not to their actual location in the coefficient matrix. The actual assignment of these subscripts is quite arbitrary; the only requirement is that they be assigned in an ascending sequence with no duplication or gaps.

In the coefficient matrix of (10), all of the diagonal elements ($a_1 - a_7$) would numerically be equal to unity. The elements in the upper-right triangle would all have negative values, while those in the lower-left triangle would be positive. The elements of the right-hand-side vector physically represent merchant production rates and would have positive or zero values, depending upon whether or not merchant production of a given commodity is intended. This example coefficient matrix is admittedly not very sparse. In practice, however, with the number of commodities of the order of 100, the resulting coefficient matrix is much sparser and would have a much larger number of elements corresponding to by-product production.

This coefficient matrix is triangularized by eliminating all of the elements in the upper-right triangle; alternately, all of the elements in the lower-left triangle could be eliminated. It has been assumed here that this matrix is nonsingular and that all of the entries of the main diagonal are nonzero. The elements in the upper-right triangle are eliminated by proceeding row by row from bottom to top, and from right to left in a given row. Thus, a_{11} is first removed by adding $-a_{11}/a_5$ times the fifth row to the fourth row. In so doing, in this case, a new value of a_{18} is created; it is also conceivable in the general case that a new element is created where none previously existed. Such new elements are merely added to the row location, column location, and coefficient value vectors in ascending sequence as they arise. In this particular case, elements a_{10}, a_{13}, a_9, a_{12} and a_8 are next eliminated in that order.

The elimination steps outlined above can be characterized by an operator string of integers corresponding to element numbers, such as is shown in Table 1. In this string, a zero designates the end of the string, and a negative sign prefixing an integer denotes a new element to be eliminated. The entry following a negative entry corresponds to the diagonal element used in the elimination procedure, and a

TABLE 1: Operator String of Integers Corresponding to the Elimination Steps Associated with Triangularization of the Example Matrix

−11	5	18	19	−10	5	17	19	
−13	6	16	20	−9	3	16	17	
−12	6	15	20	−8	3	15	17	0

TABLE 2: Operator String of Integers Corresponding to the Back-Substitution Steps Associated with Solution of the Example Matrix Equation

15	8	−1	1	16	8	−2	2
17	8	−3	3	18	8	−4	4
19	8	−5	5	20	8	−6	6
14	3	21	8	−7	7	0	

technical and economic results, such as total capital investment required, raw material costs, product values, by-product credits and total energy consumption.

8. LIMITATIONS

When the net production of a certain by-product is greater than any merchant production requirements, and that commodity is also the primary product of another manufacturing operation, the calculation procedure outlined above must be modified somewhat. A specific example here would be chlorine, which is naturally the primary product from a chlorine plant, and also a by-product in the manufacture of metallic sodium from salt (sodium chloride). When this condition occurs, as indicated from the solution vector results, another calculation pass must be made. In this second calculation pass, all of the entries in the column(s) corresponding to the material(s) falling into this category are temporarily blanked out (save for the diagonal entry), and the calculation procedure repeated. This second pass, of course, occasions no significant increase in computation time, since both operator strings (triangularization and back substitution) remain valid.

The primary limitation in the material balance calculation procedure described above results from the same assumptions underlying input-output tables. Specifically, the assumption of homogeneity requires that each sector (commodity in this case) should have a single input structure. In the construction of the data base described above, the currently most popular process for the production of each commodity was selected, with the thinking that this was probablv the most efficient such process. Different processes do exist, of course, for the manufacture of the same chemical commodity. For example, the direct oxidation of ethylene to produce acetaldehyde was described earlier; acetaldehyde can also be produced via the direct hydration of acetylene with water. Thus, the material balance calculation procedure described does not permit the ready consideration of alternate raw material sources or of alternate production processes. The development of such a capability really converts the problem from one of straightforward analysis to one of optimization. Linear programming techniques [11], still invoking the assumption of proportionality, may be of use in the resolution of this optimization problem.

9. SUMMARY

Methods which aid in the identification and analysis of potential chemical manufacturing complexes have been described. Specifically, a tool based upon graph theory to identify chemical commodities as potential candidates for manufacture in a co-sited framework has been developed. Also, the usage of sparse

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

October 14, 1978

Grants Administrator
National Science Foundation
Washington, D.C. 20550

Attention: Ms. Mary Frances O'Connell

Reference: NSF Grant No. AER76-80993
(Georgia Tech Project No. B-0488-000)

Subject: Interim Progress Report No. 3
"Systems-Integration Requirements for the Synergistic Co-Siting of Industrial Activities"

This report summarizes progress on the referenced grant project for the period April 15, 1978 through October 14, 1978.

I. Introudction

The purpose of this program is to apply advanced and comprehensive systems-integration methodology for the design of cost-effective, synergistically co-sited industrial activities. Synergistic co-siting involves the carefully planned grouping of industrial and/or agricultural activities in complexes that provide mutually beneficial utilization of energy, raw materials, co-products, land, plant wastes, and transportation facilities, as well as promote greater economical attractiveness of pollution-control measures, resource recovery, etc. Anticipated results of this study include practically achievable synergistic co-siting approaches to industrial-site planning, and to plant and process design, which offer the promise of some very effective and exciting possibilities for the simultaneous achievement of certain critical national and international goals such as resources (including energy) conservation, new energy sources, effective land use, improved food supply, improved environmental quality, and beneficial industrial development. These results, together with guidelines and recommendations for their practicable application, will be communicated appropriately to prospective users during the course of this study.

The rationale for our study involves a systematic search for, and evaluation of, industrial combinations which offer promise for grouping synergistically in some form of co-siting to satisfy total systems-integration criteria and accomplish program objectives. Our overall plan consists of a logical sequence of tasks designed to group functionally the investigative activities and facilitate the flow of the associated effort and results among these tasks. The tasks and their individual technical purposes are as follows:

Task I. Expansion of Data Base

Purpose: To compile adequate technical and economic information required as a basis for the extensive analyses that will be performed on susequent tasks, including the addition of input-output information on more production commodities as an expanded reservoir of grouping candidates.

Task II. Development of Criteria for Total Systems Integration

Purpose: To establish guidelines for screening and selecting candidate process units, as required in the coupling-matching analysis, based on realistic benefit goals and systems-integration constraints.

Task III. Coupling-Matching Analysis

Purpose: To provide candidate industrial couplings for use in developing integrated, synergistically co-sited systems designs, based upon the guidelines formulated in Task II.

Task IV. Systems Integration Analysis

Purpose: To formulate and specify design features for fully-integrated co-siting complexes which meet the Task II guidelines.

Task V. Tradeoff and Cost-Benefit Analysis

Purpose: To evaluate realistically the practical advantages and disadvantages, institutional barriers and implementational potential for each of the candidate complexes identified and characterized on Task IV, as a basis for motivating user interest and initiative in pursuing demonstration development of such complexes.

Task VI. Regional Application Analysis

Purpose: To identify and characterize any features of regional (i.e., geographic, socio-economic, etc.) specificity which favor or exclude certain types of co-siting complexes or individual industrial activities, as a basis for categorizing general and limited applicability of the results and methodology of this program.

Task VII. Formulate Recommendations and Conclusions

Purpose: To develop and organize a set of useful guidelines for the application of the results and methodology produced on this program of research.

Task VIII. Initiate Utilization Plan

Purpose: To develop and implement a vigorous, effectual time-phased activity of identifying and communicating with user groups in an effort to (1) disseminate the concepts, evaluational results and significant new industrial-development tools produced on this program, and (2) maximize the benefit potential and usefulness of these program products in as large a user community as possible.

Task IX. Prepare Final Report

Purpose: To document the procedures, results, conclusions and recommendations of the program in an effective manner and appropriately time-phased to meet the reporting requirements of the National Science Foundation.

The interrelationships among these tasks are shown in Figure 1.

II. Project Schedule and Budget Status

The project effort is currently on schedule and operating within the budget and schedule plans. The schedule plan is shown in Figure 2.

Budget status through September, 1978 is as follows:

(1)	Total Expenditures to Date:	$130,847
(2)	Expenditures by Categories:	
	(a) Salaries of Principal Investigators and other Senior Personnel	$ 39,132
	(b) Other Direct Personal Services	$ 33,030
	(c) Materials and Supplies	$ 1,120
	(d) Travel (domestic only)	$ 1,259
	(e) Computer Services	$ 353
	(f) Overhead and Benefits	$ 55,953
(3)	Total Grant Funds Remaining:	$ 68,853

III. Technical Progress to Date

Technical progress during the third six-month reporting period of the project is summarized below, by tasks, for those task items that were scheduled for activity according to the schedule plan shown in Figure 2.

Overall Progress Summary

Effort was continued on Tasks I, IV, V, VI, and VIII, and completed on Tasks II and III (each described in Section I of this report). All these efforts are on schedule and are providing the anticipated results to date.

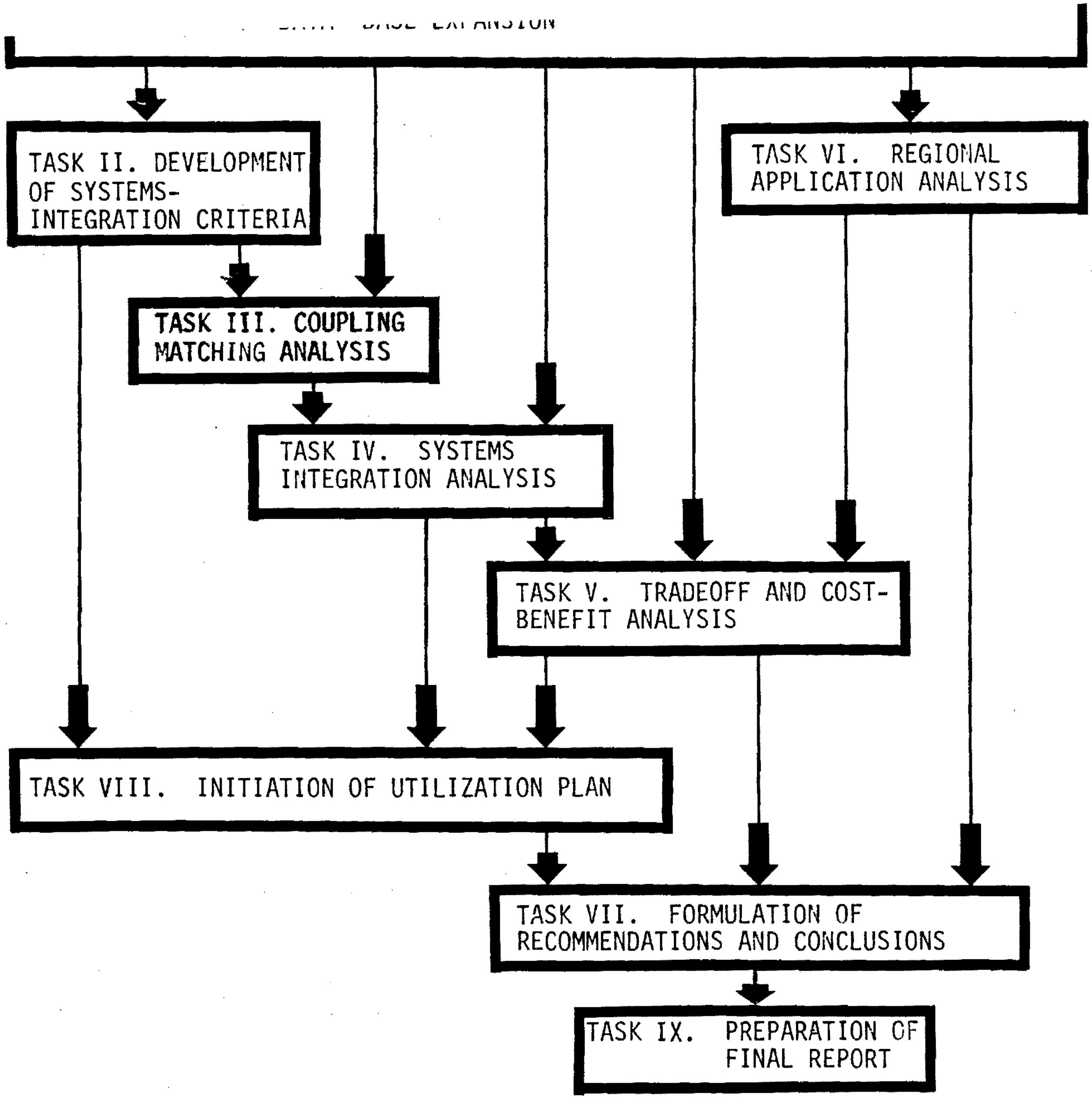

Figure 1. Task Interrelationships.

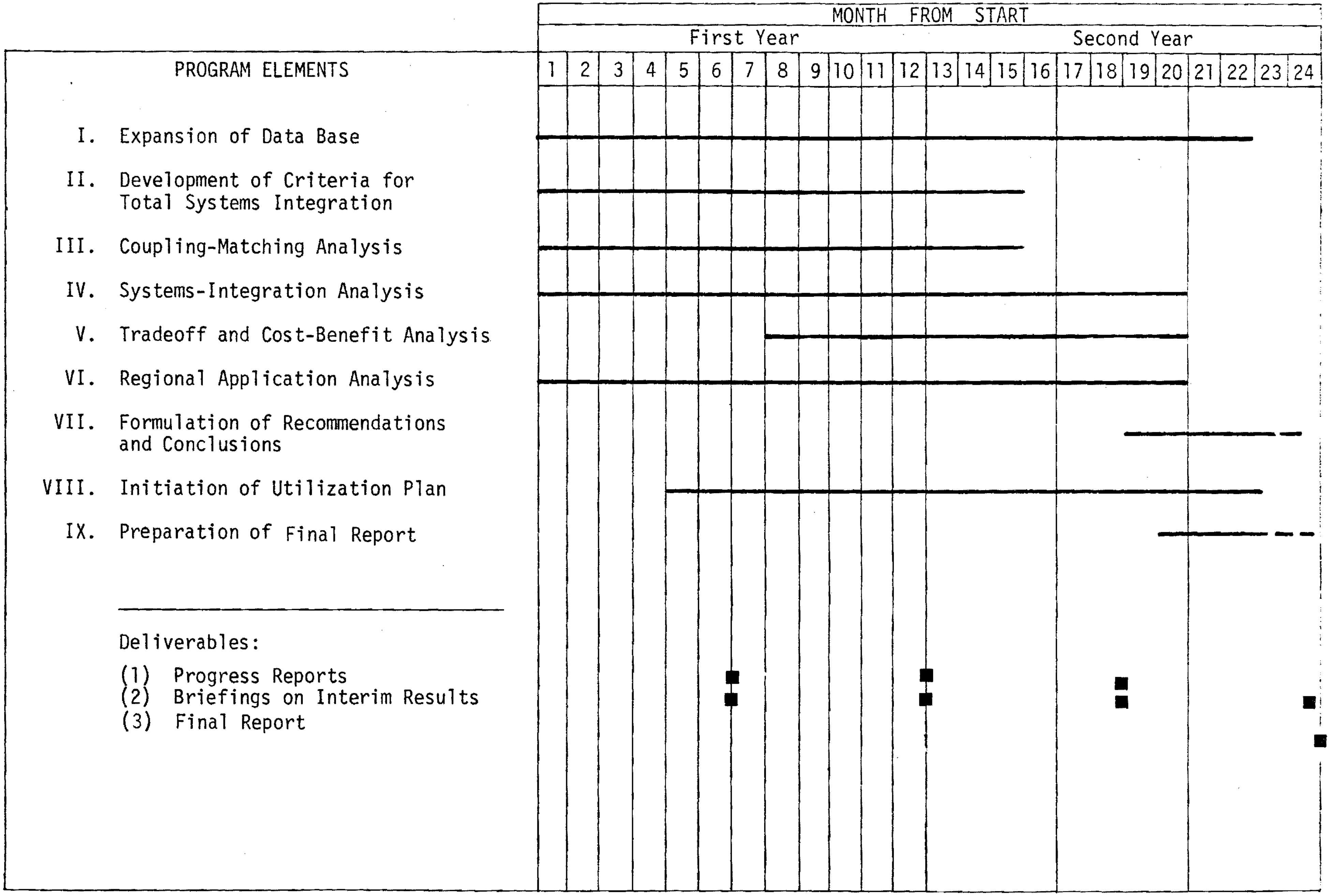

Figure 2. Program Schedule.

Tasks I, II, III, and IV are providing the information and basis required for the selection of several technically feasible candidate co-siting groupings; in addition, these tasks are producing a general methodology for such a preliminary selection process. Task V is providing information on practical advantages and disadvantages, as well as institutional barriers to industry's acceptance and implementation, of general co-siting approaches. This information is providing the basis for detailed cost-benefit and trade-off analyses for specific candidate complexes currently being studied. Task VI is providing information on local factors that affect the selection and use of land for various types of industrial sitings. These factors include costs; availability of utilities, labor force, and transportation; environmental constraints and community impact. Task VIII is providing extensive contacts and communication links with industry, federal, state, and local agencies, industrial developers and planners, and other potential user groups.

During the period September 10, 1978 to October 6, 1978, the grant project co-principal investigators visited with a number of university professors at their respective institutions in England and Scotland to discuss areas of common concern in their research and ours. Their research, sometimes called integral plant design, focuses on systematized integration of all the aspects of plant design-process selection, material and energy balances, flowsheets, equipment selection and layout, economics, control, safety, utilities, waste treatment, storage, site selection and preparation, etc. This contrasts sharply with our research on co-siting. Yet we found that their approach and ours possess so many common features that the information exchange was most beneficial to our grant project and hopefully to their endeavors. The most concrete expression of their interest in our work was an invitation to us to present a paper at the Institution of Chemical Engineers meeting to be held next September at the University of Aston in Birmingham, England. The invitation was extended by the chairman of the Design Symposium for that meeting.

Capsule summaries of important elements of progress on each initiated and completed task are presented below.

Task I. Expansion of Data Base

- Completed compilation of labor costs for industrial processes
- Continued compilation of land requirements for industrial processes
- Completed compilation and correlation of energy requirements of industrial processes
- Completed compilation of conversion factors and yields of industrial processes
- Continued compilation of state-of-the-art pollution control equipment costs
- Completed compilation of safety requirements of industrial processes
- Completed compilation of waste products of industrial processes
- Completed compilation of pollutants of industrial processes
- Updated pertinent EPA regulations for industrial processes
- Completed compilation of unit cost data for industrial processes

Task II. Development of Criteria for Total Systems Integration

- Completed compilation and analysis of flow sheets to identify matching interfaces
- Completed investigation of interfaces based on pollutant utilization schemes
- Completed investigation of interfaces based on fuel and energy utilization schemes
- Completed identification and study of specific interfaces based on feedstock alternatives

- Completed analysis of plant equipment layout
- Completed investigation of industrial/agricultural/food processing interfaces
- Completed investigation of process modifications resulting from interfacing options
- Completed investigation of time phasing of interfacing

Task III. Coupling-Matching Analysis

- Completed refinement of connection-order analysis procedures
- Completed modification of computer model to accommodate alternative production schemes as basis for optimization
- Completed refinement of methodology to incorporate total systems integration criteria
- Completed analysis of constraints associated with matching of process interfaces
- Completed development of improved matching and grouping format for computer model

Task IV. Systems-Integration Analysis

- Continued analysis of optimization factors
- Completed selection and preliminary analysis of specific total-system combinations based on feedstock alternatives, including coal (hard and lignite), fuel oil, naphtha, municipal waste, and biomass
- Completed adaptation of cost-estimating methods
- Continued investigation of design flexibility requirements
- Continued analysis of time-phasing to achieve integration goals
- Completed compilation of data on safety requirements, procedures, and regulations for industrial processes

Task V. Tradeoff and Cost-Benefit Analysis

- Continued development of preliminary cost-benefit model for candidate co-sited complexes
- Incorporated important tradeoff factors, based on discussions with Overview Committee, for integration and siting of complexes

Task VI. Regional Application Analysis

- Continued analysis of industrial site selection criteria
- Continued analysis of data on regional constraints and impacts
- Continued analysis of land availability and costs
- Continued characterization of availability of utilities
- Continued characterization of availability of labor
- Continued characterization of availability of transportation
- Continued incorporation of industry and federal-agency viewpoints based on Overview Committee's inputs

Task VIII. Initiation of Utilization Plan

- Completed arrangements for second meeting of project Overview Committee to be held at Georgia Tech on 10/27/78
- Three papers by project team submitted for publication
- Continued communications with federal, state, and local agencies involved in industrial planning and development
- Continued planning for user workshop conference to be held at Georgia Tech at a date to be coordinated with regional planners

IV. Plans for Next Reporting Period

During the next six-month reporting period on this project, October 15, 1978 through April 14, 1979, the following efforts are planned:

- Completion of all uncompleted Tasks on project
- Complete planning, development and arrangements for user workshop conference on project results; conduct this workshop at Georgia Tech in early 1979
- Complete in-depth studies of selected systems
- Develop user-interactive computer program
- Prepare and submit final report

No significant problems have been encountered to date on this project, and originally anticipated progress and results are being achieved. No problems are anticipated for the next six months of activity on the project.

Yours very truly,

Jack M. Spurlock, Ph.D.
Henderson C. Ward, Ph.D.
Co-Principal Investigators

ɜCIENCE FOUNDATION
ıgton, D.C. 20550

˜ˈNAL PROJECT REPORT
NSF FORM 98A

PLEASE READ INSTR .S ON REVERSE BEFORE COMPLETING

PART I–ˀ . IDENTIFICATION INFORMATION

and Address	2. NSF Program	3. NSF Award Number
ı Institute of Technolɯʒ, ı, Georgia 30332	Directed & Applied Research	DAR-7680993 A01
	4. Award Period From 4/15/77 To 4/30/80	5. Cumulative Award Amount $199,700

ιe

ɜ-Integration Requirements for the Synergistic Co-Siting of Industrial Activities

PART II–SUMMARY OF COMPLETED PROJECT *(FOR PUBLIC USE)*

ſhe purpose of this program was to extend and broaden research to date on gistic co-siting, which is the mutually beneficial location and coupling dustrial activities (including agricultural operations). The specific tive of the program was the development and demonstration of methodology he systems-integrated design and evaluation of cost-effective, gistically-coupled industrial complexes.

The basis of the research program, which consisted of a logical sequence sks, was systems integration. The study showed that: (1) synergistic ting of industrial activities has excellent potential for achieving both l and economic benefits in the design of industrial complexes; (2) systems-ration criteria and techniques, based on modularization, provided an tive basis for the methodology that was developed and demonstrated in this . The methodology was demonstrated in sample analyses through a user-ıctive computer mode; (3) sensitivity analyses, of the type used in this , provide a very effective method for characterizing the effects of data ty and specifying data-base requirements; (4) the Allen/Page cost estimating ique was a sufficiently detailed and convenient method for realistically ıting costs of modified or unconventional processes for which no literature ıata were available; (5) the co-siting methodology developed on this study ˜ticularly attractive for the evaluation of alternative energy sources. ɜ recommended that this methodology be extended through future studies.

PART III–TECHNICAL INFORMATION *(FOR PROGRAM MANAGEMENT USES)*

ITEM *(Check appropriate blocks)*	NONE	ATTACHED	PREVIOUSLY FURNISHED	TO BE FURNISHED SEPARATELY TO PROGRAM	
				Check (√)	Approx. Date
ɔf Theses					
ı Citations					
ientific Collaborators					
·n on Inventions					
Description of Project and Results					
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vestigator/Project Director Name *(Typed)*	3. Principal Investigator/Project Director Signature	4. Date
purlock and H. C. Ward		7/15/80

(5-78) Supersedes All Previous Editions — Form Approved OMB No. 99R0013

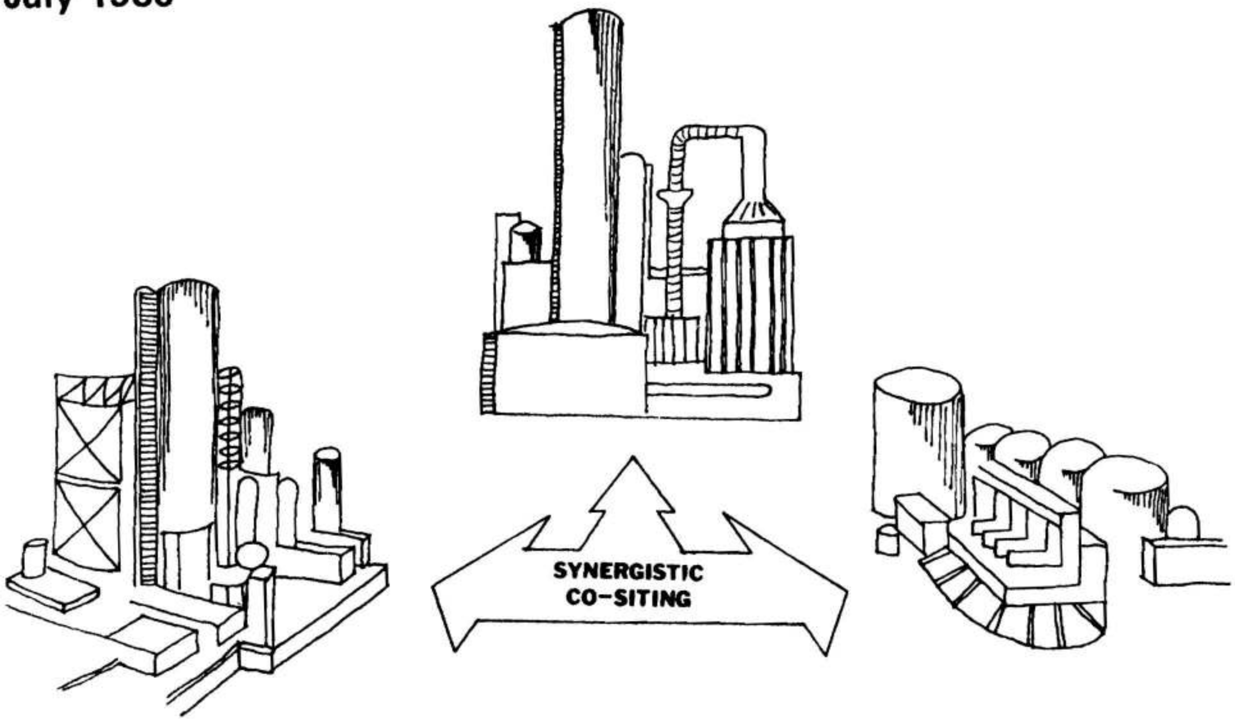
FINAL REPORT

SYSTEMS–INTEGRATION REQUIREMENTS FOR THE SYNERGISTIC CO–SITING OF INDUSTRIAL ACTIVITIES

By

J. M. Spurlock and H. C. Ward, Principal Investigators
J. T. Sommerfeld and D. K. Sondhi

July 1980

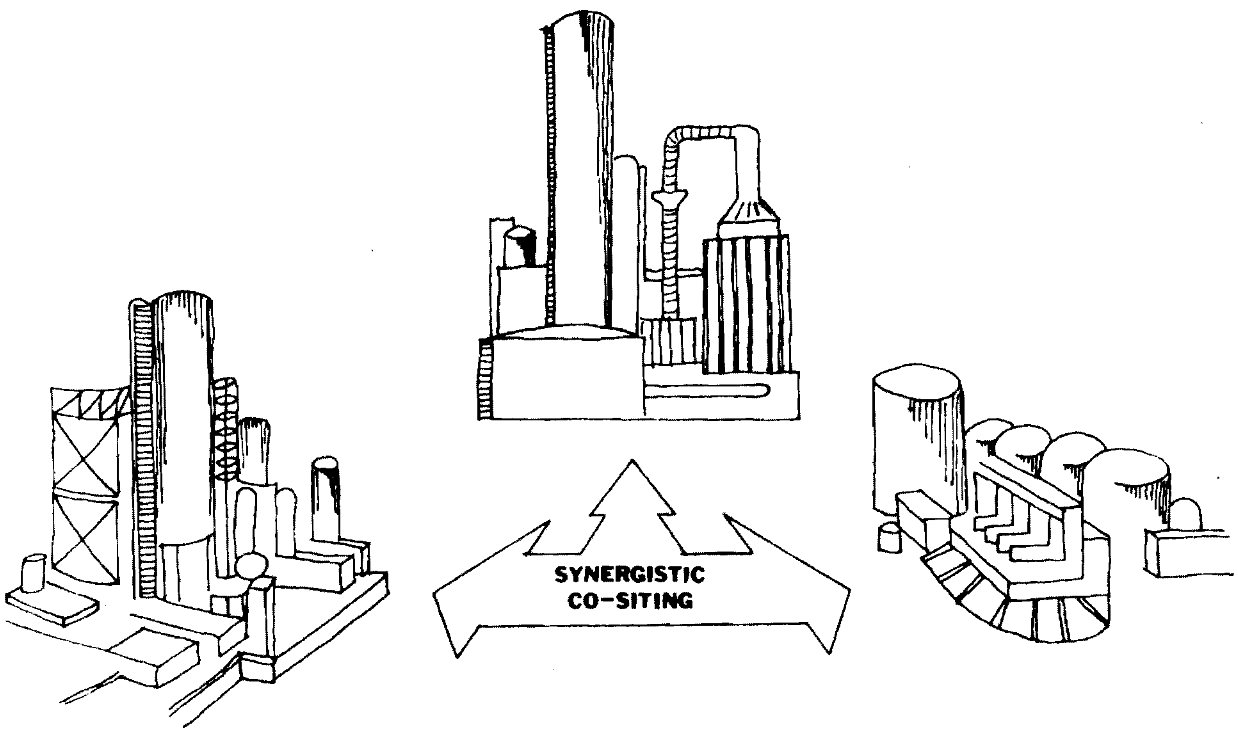


GEORGIA INSTITUTE OF TECHNOLOGY

Engineering Experiment Station
Atlanta, Georgia 30332

National Science Foundation, Grant Number DAR–7680993 A01
Georgia Tech Project B–488–000

SYSTEMS-INTEGRATION REQUIREMENTS FOR THE SYNERGISTIC CO-SITING OF INDUSTRIAL ACTIVITIES



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EXECUTIVE SUMMARY

The purpose of this program, conducted for the National Science Foundation, was to extend and broaden Georgia Tech's research to date on the concept of synergistic co-siting. By our definition, synergistic co-siting is the carefully planned grouping of industrial activities, including agricultural operations, co-located in complexes to simultaneously promote:

(1) mutually beneficial utilization of energy, raw materials, co-products, land, plant wastes and effluents, and transportation facilities through the synergistic location and coupling of the input and output streams; and

(2) greater economic attractiveness of innovative approaches such that industry will have new incentives for voluntarily implementing pollution-control and energy-conservation measures, resource recovery, etc.

Approaches to industrial plant and process design, as well as site planning, based on synergistic co-siting, offer the promise of some very effective and exciting possibilities for the simultaneous achievement of certain critical national and international goals such as resources (including energy) conservation, alternative energy sources, effective land use, improved food supply, improved environmental quality, and beneficial industrial development.

The basis of our research program is systems integration. The general concept of systems integration involves the design of complicated, highly interactive systems through the analysis of requirements for optimum functional and cost-effective performance of the entire system, rather than each component sub-system. In contrast, current conventional practice involves the design of individual processing units of an industrial complex to achieve technically and economically acceptable production efficiency

for that unit; then the units are combined by the coupling of their shared raw-material, feedstock and product streams to form industrial complexes. This latter approach provides very little flexibility for changes in design and operation to meet the demands of environmental control, changes in the availability of sources of fuels and feedstocks, changes in the market for products, etc., without economic penalties.

The specific objective of the program were:

(1) the development of methodology for the systems-integrated design and evaluation of cost-effective, synergistically-coupled industrial complexes; and

(2) the formation, documentation and communication of recommendations and guidelines for use of this methodology an an important new tool for industrial development activities.

The program was conducted by a multidisciplinary project team from the Engineering Experiment Station (EES) of the Georgia Institute of Technology. Throughout the program, interaction increased between the EES project staff, NSF and appropriate federal, state, and local agencies involved in industrial planning and development. This interaction, along with meetings with a Project Overview Committee, was important in guiding the alignment and orientation of the investigative effort and particularly useful in the selection of specific co-siting applications.

The following tasks were conducted during the course of the program:

Task I -- Expansion of Data Base;

Task II -- Development of Criteria for Total Systems Integration;

Task III -- Coupling-Matching Analysis;

Task IV -- Systems Integration Analysis;

Task V -- Tradeoff and Cost-Benefit Analysis;

Task VI -- Regional Application Analysis;

Task VII -- Formulation of Recommendations and Conclusions;

Task VIII -- Initiation of Utilization Plan;

Task IX -- Preparation and Distribution of Final Report

Task I. Expansion of Data Base

The data base was expanded to include pertinent technical and economic information on 186 industrial commodities. These data were obtained from a variety of literature sources and handbooks, then filed and catalogued for easy and rapid accessing. For 63 of these commodities, cost data was obtained using the Allen/Page cost estimation method. For the remainder, historical cost data was obtained where available from published sources. This task supplied data and background information directly or indirectly to all of the tasks of this study.

Task II. Development of Criteria for Total Systems Integration

Guidelines were established for screening and selecting candidate industrial processing units, based on realistic benefit goals and systems-integration constraints. Principal interfaces for the coupling of industrial activities into synergistic complexes were characterized as the basis for selecting candidate co-siting groupings of these units to achieve technical and economic benefits.

Task III. Coupling-Matching Analysis

This analysis provided candidate industrial couplings for use in developing integrated, synergistically co-sited systems designs, based upon the guidelines of Task II. The input-output data obtained from the data base was used to accomplish automated or manual matching of appropriate interfaces for candidate processes.

Task IV. Systems Integration Analysis

This task involved the combination of the essential results from Tasks I, II, and III for the formulation and specification of key design features of integrated, synergistically co-sited industrial complexes. As in the case of Task III, the methodology employed both automated and manual procedures for the development of these integrated-systems design concepts. One of the most important techniques used in this analysis was modularization. This technique involved the integration of candidate couplings into progressively more sophisticated but feasible and practically-achievable functional modules.

Task V. Tradeoff and Cost-Benefit Analysis

This task involved a careful, rigorous screening process together with the requirement that certain key selection criteria be met to evaluate the potential technical and economic viability of candidate co-sited complexes that were identified and characterized on Task III. This evaluation process involved a combination of tradeoff analysis and cost-benefit analysis. Sensitivity analyses also were performed to determine the effect of data quality on the economic assessment.

Task VI. Regional Application Analysis

Efforts on this task elucidated region-specific factors that influence individual and complexed industrial plant sitings. These factors, determined from the data-base information, were geographical, policy and regulatory, market, supply and transportation constraints.

Task VII. Formulation of Recommendations and Conclusions

Essential recommendations and conclusions are summarized at the end of this Executive Summary.

Task VIII. Initiation of Utilization Plan

A vigorous, effectual time-phased activity of identifying and communicating with user groups was developed and implemented. Specific activities included two meetings of the Project Overview Committee; communications with federal, state, and local agencies involved in industrial planning and development; participation in pertinent national meetings and conferences; publication and presentation of several project papers; radio presentation of co-siting concepts; and visits with university professors in England and Scotland who are working in related areas.

The major objectives of the analyses performed in these task efforts were to develop methodology and to demonstrate key aspects of this methodology, using several specific examples, with emphasis on application potential. The scope of the project budget and schedule did not permit the use of the methodology to characterize an optimized complex for a particular region. The specific elements of the methodology emphasized in the example analyses included:

- Selection of candidate groupings.
- Comparison of alternative grouping schemes with respect both to stream interfacing and investment costs.
- Application of systems-integration criteria based on modularization.
- Procedures for effective sensitivity analyses to characterize the effects of data quality (reliability).
- Refinement of the previously developed user-interactive computer program for application of methodology.

- Identification of items requiring further refinement and study.

The essential conclusions that were derived from the results of this study can be summarized as follows:

- Synergistic co-siting of industrial activities has excellent potential for achieving both social and economic benefits in the design of industrial complexes.

- Systems-integration criteria and techniques, based on modularization, provided an effective basis for the methodology that was developed in this study, and it is recommended that this methodology be extended through future studies. Our methodology works well in a user-interactive computer mode, as demonstrated in the example analyses that were performed on this study.

- Sensitivity analyses, of the type used in this study, provide a very effective method for characterizing the effects of data quality and specifying data-base requirements.

- The Allen/Page cost estimating technique is a sufficiently detailed and convenient method for realistically estimating costs of modified or unconventional processes for which no literature cost data are available. This method worked well in both the automated and manual modes employed in this study.

- The co-siting methodology developed on this study is particularly attractive for the evaluation of alternative energy sources. For example, where the availability of feedstocks is regionally dependent, the methodology would be useful in identifying and assessing the net benefits that could result from the design of co-sited complexes that can use a variety of feedstocks.

During the course of this program we have identified advanced design issues requiring in-depth studies and advanced new methodology development that were beyond the available time of our funding resources. These issues are: criteria for optimal sizing and design of co-sited plants; identification of need and criteria for extremely efficient new processes; heuristics for relationships among industry, community planners, and government regulatory agencies; dynamic modelling of co-sited complexes; and co-siting concepts for low-level waste heat utilization. Therefore, it is recommended that the methodology development efforts of the present study be the basis for a new research program having the following specific objectives: (1) to develop, based on advanced concepts for synergistically co-sited industrial activities, a generalized methodology for predictive designs which transcend tradeoff compromises while simultaneously achieving economic benefits (including profitability) and conservation and environmental goals through innovative responses to technical, economic and social forcing functions which, combined, impact on industrial viability; and (2) to demonstrate the methodology through designs and application analyses for carefully selected systems.

1.0 INTRODUCTION

1.1 Purpose, Objectives and Scope of the Investigation

The purpose of this program, conducted for the National Science Foundation, was to extend and broaden Georgia Tech's research to date 1,2/ (references are listed in Appendix A) on the concept of synergistic co-siting (i.e., mutually beneficial location and coupling of the input and output streams) of industrial plants, and other related activities, as an important and promising approach for the solution of major national problems such as energy and resources conservation, environmental quality, land use, and effective industrial development. The specific objectives of the program were:

(1) the development of methodology for the systems-integrated design and evaluation of cost-effective, synergistically-coupled industrial complexes; and

(2) the formation, documentation and communication of recommendations and guidelines for use of this methodology as an important new tool for industrial development activities.

The program was conducted for the NSF by a multidisciplinary project team from the Engineering Experiment Station (EES) of the Georgia Institute of Technology. Throughout the program, interaction increased between the EES project staff, NSF and appropriate federal, state, and local agencies involved in industrial planning and development. This interaction along with meetings with an Overview Committee* was important in guiding the alignment and

*The roster of the Overview Committee is given in Appendix B along with minutes of its two meetings.

orientation of the investigative effort and particularly useful in the selection of specific co-siting applications.

1.2 Background

This report describes a program of interdisciplinary study on the concept or synergistic co-siting of industrial activities as an important and promising approach for the solution of major national problems. By our definition, synergistic co-siting is the carefully planned grouping of industrial activities, including agricultural operations, co-located in complexes to simultaneously promote:

(1) mutually beneficial utilization of energy, raw materials, co-products, land, plant wastes and effluents, and transportation facilities; and

(2) greater economic attractiveness of innovative approaches such that industry will have new incentives for voluntarily implementing pollution-control and energy-conservation measures, resource recovery, etc.

Approaches to industrial plant and process design, as well as site planning, based on synergistic co-siting, offer the promise of some very effective and exciting possibilities for the simultaneous achievement of certain critical national and international goals such as resources (including energy) conservation, alternative energy sources, effective land use, improved food supply, improved environmental quality, and beneficial industrial development. A hypothetical example of synergistic co-siting is shown in Figure 1-1.

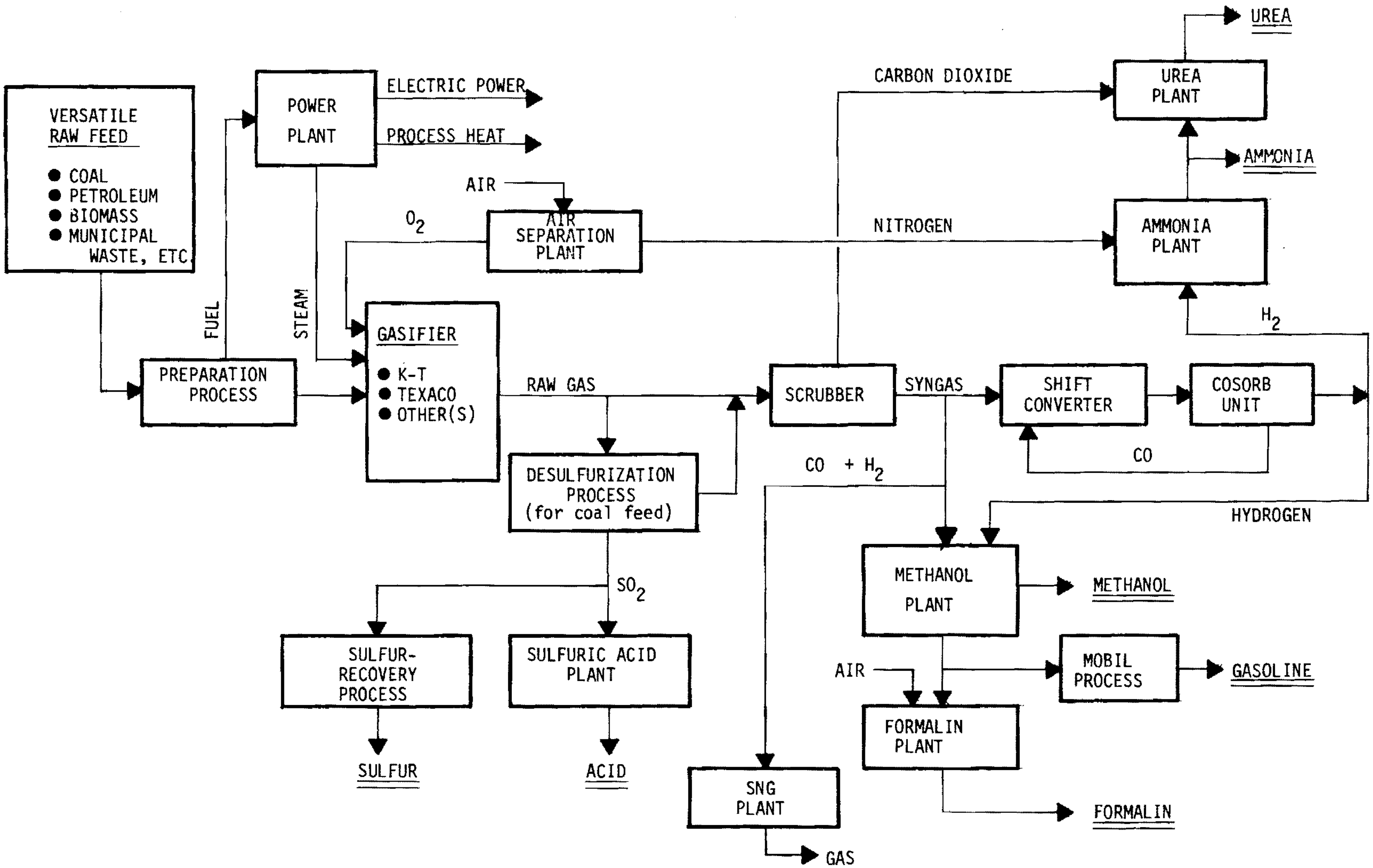

Figure 1-1. Hypothetical Example of a Synergistically Co-Sited Complex Based on Synthesis-Gas Feedstock from Either Coal, Petroleum, Biomass or Municipal Waste

The basis of our research program is systems integration. The general concept of systems integration involves the design of complicated, highly interactive systems through the analysis of requirements for optimum functional and cost-effective performance of the entire system, rather than each component sub-system. In contrast, current conventional practice involves the design of individual processing units of an industrial complex to achieve technically and economically acceptable production efficiency for that unit; then the units are combined by the coupling of their shared raw-material, feedstock and product streams to form industrial complexes. This latter approach provides very little flexibility for changes in design and operation to meet the demands of environmental control, changes in the availability of sources of fuels and feedstocks, changes in the market for products, etc., without economic penalties.

The principal fundamental, pioneering developmental efforts on systems-integration methodology were associated with the defense and space programs of the past 15 to 20 years. For the extremely complex systems that were required for these programs, it was discovered that design and operational flexibility and performance reliability were critically important features. Furthermore, it was determined that these features were more predictably obtainable from (1) a careful analysis, at the outset of design studies, of overall system optimization requirements; and (2) the design of all sub-systems to satisfy these requirements upon integration into the system. Very often this required highly flexible sub-systems designs to provide the needed contingencies and circumvent the need for emergency retrofits (which are almost always sub-optimum and characterized by performance and economic penalties). For example, these contingencies might be required to satisfy unanticipated but critically impacting mission changes, off-baseline operational conditions, and human-factors considerations. It was also learned that systems analyses very often identified opportunities and techniques for "synergistically" combining sub-systems; that is, in a manner such that the two units performed better when co-designed and operated together than in the independent mode.

The generalized components of state-of-the-art systems-integration methodology for the design of complex systems are essentially the following:

- Defining the overall performance requirements for the system.
- Defining the baseline operating "environment" in which the system must function, as well as contingency requirements to provide needed flexibility should this environment change significantly from baseline conditions.
- Specifying functional requirements and design criteria for individual sub-systems.
- Modelling the interaction of sub-systems, at their coupling interfaces, to select optimum combinational criteria and techniques and identify opportunities for synergism.
- Iterative design of the integrated system through the formation, evaluation and comparison of various design scenarios, from which the best design (having the overall optimum tradeoff characteristics with respect both to technical and economic considerations) is selected.

The modes which provide the basis for the application of co-siting methodology include:

(1) matching existing plants within a limited geographical area;

(2) matching existing or presently proposed plants with new plants; and

(3) development of entirely new complexes.

We hypothesize that the application of systems-integration methodology to these co-siting modes can provide some very important benefits for industry, the nation, and the world. Examples of the national benefits anticipated from the application of fully-integrated synergistic co-siting methodology are listed in Table 1-I.

The methodology, results and essential conclusions and recommendations of this study are discussed in the remaining sections of this report.

TABLE 1-I

POTENTIAL BENEFITS OF SYNERGISTIC CO-SITING

- Energy conservation
- Development of new sources of feedstocks
- Economical resource and waste recovery
- Improved methods of (and incentive for) pollution control
- Improved land use
- Optimization of transportation use
- Electrical-power cost advantages
- Improved stability of labor pools and job opportunities
- Increased incentive for car-pooling
- Improved basis for use of high-temperature gas-cooled nuclear reactors
- Improved basis for community planning
- Reduction in site-approval time for new plants
- Improved basis for attracting new industry and increased plant sitings
- More economical basis for plant services
- Agricultural benefits
- Improved product mix
- Lower unit product cost
- Reduction of off-site facilities cost

2.0 DESCRIPTIONS OF PROJECT TASKS AND METHODOLOGY DEVELOPMENT

2.1 Rationale and Task Structure

The problem of predicting the practical effects of industrial co-siting, and evaluating the cost-effectiveness of its applications on any reasonable scale, is extremely complicated. The facets, both technical and economic, which contribute to such an analysis are multiple and iterrelated in complex ways. For example, there are numerous choices of industrial processes that can be grouped together for some synergistic purposes. We have determined, however, that a careful design analysis, based on total systems - integration criteria, eliminates a significant number of these choices.

The rationale for our study involved a systematic search for, and evaluation of, industrial combinations which offered promise for grouping synergistically in some form of co-siting to satisfy total systems-integration criteria and accomplish the overall program objectives specified in Section 1.1. Our research plan consisted of a logical sequence of tasks designed to group functionally the investigative activities and facilitate the flow of the associated effort and results among these tasks. These tasks and their individual technical purposes were as follows:

Task I. Expansion of Data Base

Purpose: To compile adequate technical and econimic information required as a basis for the extensive analyses to be performed on subsequent tasks, including the addition of input-output information on more production commodities as an expanded reservoir of grouping candidates.

Task II. Development of Criteria for Total Systems Integration

Purpose: To establish guidelines for screening and selecting candidate process units, as required in the coupling-matching analysis, based on realistic benefit goals and systems-integration constraints.

Task III. Coupling-Matching Analysis

Purpose: To provide candidate industrial couplings for use in developing integrated, synergistically co-sited systems designs, based upon the guidelines formulated in Task II.

Task IV. Systems Integration Analysis

Purpose: To formulate and specify design features for fully-integrated co-siting complexes which meet the Task II guidelines.

Task V. Tradeoff and Cost-Benefit Analysis

Purpose: To evaluate realistically the practical advantages and disadvantages, institutional barriers and implementational potential for each of the candidate complexes identified and characterizaed on Task IV, as a basis for motivating user interest and initiative in pursuing demonstration development of such complexes.

Task VI. Regional Application Analysis

Purpose: To identify and characterize any features of regional (i.e., geographic, socio-economic, etc.) specificity which favor or exclude certain types of co-siting complexes or individual industrial activities, as a basis for categorizing general and limited applicability of the results and methodology of this program.

Task VII. Formulate Recommendations and Conclusions

Purpose: To develop and organize a set of useful guidelines for the application of the results and methodology produced on this program of research.

Task VIII. Initiate Utilization Plan

Purpose: To develop and implement a vigorous, effectual time-phased activity of identifying and communicating with user groups in an effort to (1) disseminate the concepts, evaluational results and significant new industrial-development tools produced on this program, and (2) maximize the benefit potential and usefulness of these program products in as large a user community as possible.

Task IX. Prepare Annual and Final Reports

Purpose: To document the procedures, results, conclusions and recommendations of this study in an effective manner.

The interrelationships among these tasks are shown in Figure 2-1. The efforts on Task I through IV resulted in the development of a methodology for the identification of potential co-siting candidates and analytical methods for investigation of technical and economic benefits resulting from various co-siting groupings.

The tasks and the methodology development are described in the following sections.

2.2 Task I - Expansion of Data Base

As shown in Figure 2-1, this task supplies data and background information directly to Tasks II through VI, and indirectly to all the

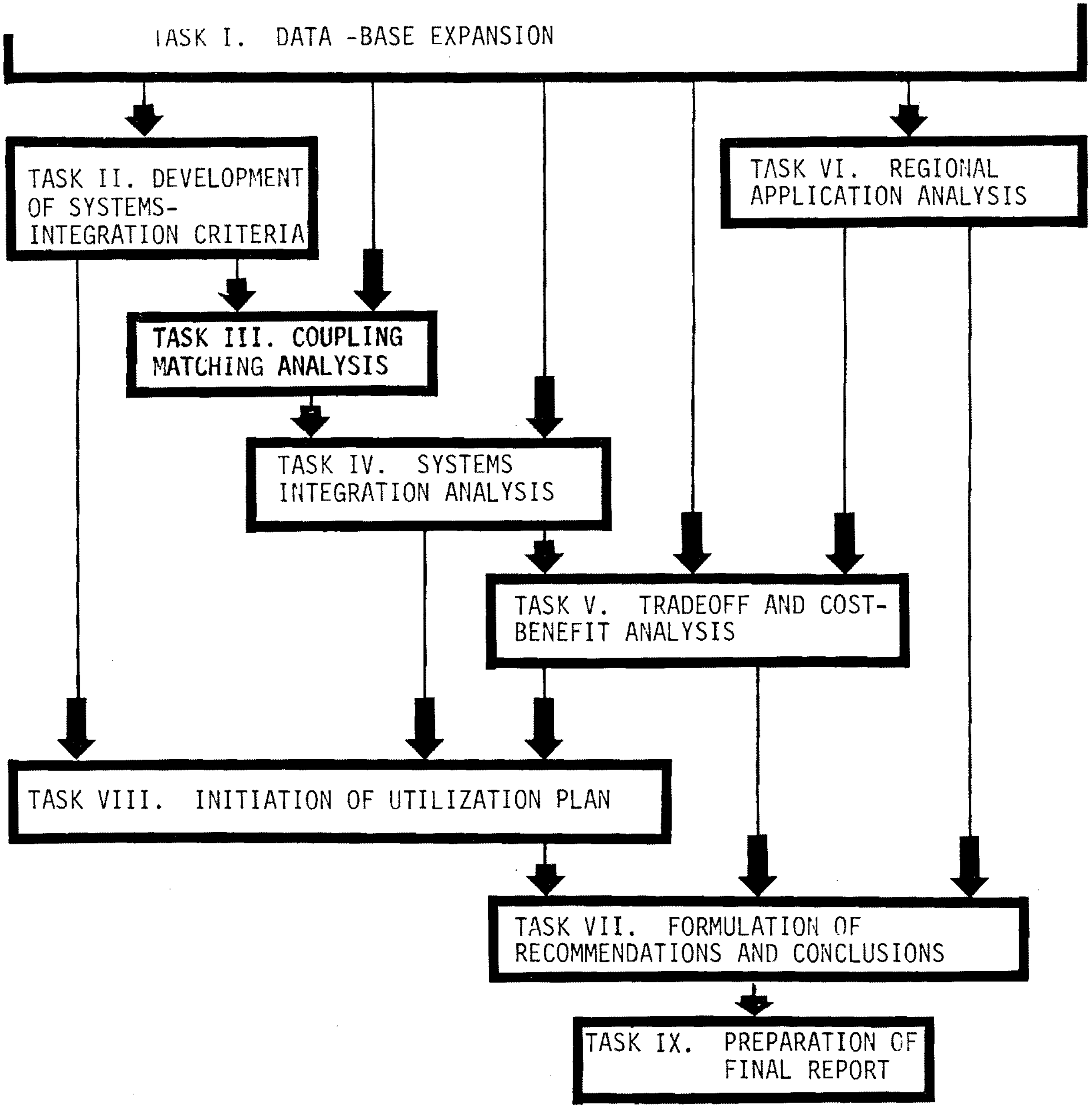

Figure 2-1. Task Interrelationships for Research Plan

other tasks of this study. In our previous study 1,2/ for the Appalachian Regional Commission, the development of a data base consistent with the objectives of that program was an essential aspect of the effort accomplished. This data base contained information on 88 industrial chemical commodities and was computerized. The various information items stored for each of these commodities are characterized in Table 2-I. The cost data for each of these commodities was obtained from various published sources and is therefore termed historical. On the present program this data base was expanded to include 186 commodities, again with historical cost data 3-9/ when such was available. The commodities in this data base are shown in Table 2-II. In order that the data and information requirements of Tasks II, III and IV, in particular, could be met, it was necessary to abandon the use of historical cost data and provide means of estimating costs of modified processes such that advantages of process interfacing could be realistically accounted for. As discussed later in Section 2-5, the Allen/Page cost estimation method 10/ was chosen for this purpose and even though the flow-sheet analysis required for its application is very time consuming, cost estimates were made for 63 processes using this method. These cost estimates are given in Table 2-III along with historical cost data for comparison purposes. The Allen/Page parameters used in making these estimates are summarized in Table 2-IV. Thirteen of these processes, indicated by (superscript +) in Tables 2-III and 2-IV, along with three raw materials and three by-product commodities were computerized for use in the methodology demonstration example of Section 3.2.

Information for the additional data base requirements of Task II as well as those of Tasks V and VI concerning energy use and conservation measures, pollution controls and standards, federal regulations, site

TABLE 2-I

DATA-BASE ENTRIES FOR EACH COMMODITY AND EXAMPLE PRINTOUT FOR A SPECIFIC COMMODITY

A. DATA BASE ENTRIES FOR EACH COMMODITY

Capacity of baseline production facility, tons/yr

Capital cost of baseline production facility, MM$

Marshall-Swift index for the capital cost

Exponent in the power-law relationship between production plant capital cost and capacity

Selling price of the commodity, ¢/lb

Unit energy requirements for production of the commodity, kwh/ton

Raw material requirements, lb/lb

By-product production, lb/lb

B. EXAMPLE PRINTOUT FOR A SPECIFIC COMMODITY

ETHYLENE OXIDE

BASELINE PLANT CAPACITY	=	100000 TONS/YEAR
BASELINE PLANT COST	=	30.00 MILLION DOLLARS
CAPACITY/COST EXPONENT	=	0.78
MARSHALL-SWIFT INDEX	=	303.3 (1970)
SELLING PRICE	=	26.00 CENTS/LB (1975)
ENERGY REQUIREMENT	=	1700 KWH/TON

RAW MATERIAL REQUIREMENTS (LB/LB)

ETHYLENE	.955
OXYGEN	2.543

BY-PRODUCT PRODUCTION (LB/LB) -

CARBON DIOXIDE	.999

TABLE 2-II

ALPHABETICAL LISTING OF DATA BASE COMMODITIES
WITH HISTORICAL COST DATA WHEN AVAILABLE

Commodity	Commodity
Acetaldehyde	Aspirin
Acetic Acid	Bauxite
Acetic Anhydride	Benzene
Acetone	Benzoic Acid
Acetonitrile	Benzyl Chloride
Acetylene	Bisphenol A
Acrylamide	BTX Fraction
Acrylic Acid	Butadiene
Acrylonitrile	n-Butanol
Adipic Acid	s-Butanol
Adiponitrile	t-Butanol
Air	i-Butane
Allyl Chloride	n-Butene
Alumina	n-Butyl Acrylate
Aluminum Sulfate	n-Butyraldehyde
Ammonia	Calcium Carbide
Ammonium Bisulfate	Calcium Carbonate
Ammonium Chloride	Calcium Cyanamide
Ammonium Nitrate	Calcium Fluoride
Ammonium Phosphate	Calcium Hydroxide
Ammonium Sulfate	Calcium Oxide
Aniline (I)	Calcium Phosphate
Aniline (II)	Calcium Silicate
Aniline (III)	Calcium Sulfate
Aniline	Caprolactam
Argon	Carbitol

(Continued)

TABLE 2-II (Continued)

ALPHABETICAL LISTING OF DATA BASE COMMODITIES
WITH HISTORICAL COST DATA WHEN AVAILABLE

Commodity	Commodity
Carbon Black	Epichlorohydrin
Carbon Dioxide	Ethane
Carbon Disulfide	Ethanol
Carbon Monoxide (I)	Ethyl Acetate (I)
Carbon Monoxide (II)	Ethyl Acetate (II)
Carbon Monoxide	Ethyl Acetate
Carbon Tetrachloride	Ethyl Acrylate
Chlorine (I)	Ethyl Cellosolve
Chlorine (II)	Ethyl Chloride
Chlorine	Ethyl Ether
Chloroform	2-Ethyl - 1-Hexanol
Chloroprene	Ethylbenzene
Choline Chloride	Ethylene
Coal	Ethylene Carbonate
Coke	Ethylene Dichloride
Cumene	Ethylene Glycol
Cyclohexane	Ethylene Oxide
Diammonium Phosphate	Ethylenediamine
Dichlorobenzene	Ethyleneimine
Dichlorodifluoromethane	Ethylmercaptan
Diethyl Sulfide	Formaldehyde
Dimethyl Formamide	Formic Acid
Dimethyl Terephthalate	Glycerine
Dimethylamine	Hexamethylenediamine
Diphenylamine	Hydrazine
Dodecene	Hydrogen

(Continued)

TABLE 2-II (Continued)

ALPHABETICAL LISTING OF DATA BASE COMMODITIES
WITH HISTORICAL COST DATA WHEN AVAILABLE

Commodity	Commodity
Hydrogen Chloride	Nitric Acid
Hydrogen Cyanamide	Nitrobenzene
Hydrogen Fluoride	Nitrogen
Hydrogen Peroxide	Nonene
Hydrogen Sulfide	Oxygen
Hydroxylamine Sulfate	Pentacrythritol
Hypochlorous Acid	Peracetic Acid
Isoprene	Perchloroethylene
Isopropanol	Phenol
Lactic Acid	Phosgene
Lactonitrile	Phosphoric Acid
Maleic Anhydride	Phosphorus
Melamine	Phosphorus Pentoxide
Metaldehyde	Phthalic Anhydride
Methane	Polyacrylonitrile
Methanol	Polybutadiene
Methyl Acrylate	Polyethylene (HD)
Methyl Chloride	Polyethylene (LD)
Methyl Ethyl Ketone	Polyisoprene
Methyl Isobutyl Ketone	Polypropylene
Methyl Methacrylate	Polystyrene
Methylamine	Polyvinyl Chloride
Methylene Dichloride	Potassium Chloride
Monochloroacetic Acid	Potassium Hydroxide
Monochlorobenzene	Propane
Monoethanolamine	Propylene

(Continued)

TABLE 2-II (Concluded)

ALPHABETICAL LISTING OF DATA BASE COMMODITIES
WITH HISTORICAL COST DATA WHEN AVAILABLE

Commodity	Commodity
Propylene Glycol	Sulfur Dioxide
Propylene Oxide	Sulfuric Acid
Salicylic Acid	Terephthalic Acid
Silica	Tetrahydrofuran
Sodium	Toluene
Sodium Carbonate	Trichloroethylene
Sodium Chlorate	Trichlorofluoromethane
Sodium Chloride	Trimethylamine
Sodium Formate	Urea
Sodium Hydroxide	Vinyl Acetate
Sodium Hypochlorite	Vinyl Chloride
Sodium Silicate	Water
Sodium Sulfate	m-Xylene
Styrene	o-Xylene
Sulfur	p-Xylene

TABLE 2-III

COMPARISON OF ALLEN/PAGE COST ESTIMATES WITH REPORTED LITERATURE VALUES

			Capital Cost Estimates (1976, M$)			
Product(s)	Reactants	Production Rate, tons/yr	Allen/ Page	Others	Ref	Comments
Ammonia[+]	N_2, H_2	500,000	75,630			
DD[*] Syngas[+]	Raw Syngas	3,485,000	79,630			
Formaldehyde[+]	MeOH, Air	100,000	7,350	31,100	4	
				23,340	3	
				1,837	7	Size factor of 0.7 assumed
				2,940	9	
Gasoline[+]	Methanol	1,150,000	29,220	28,000	8	
Hydrogen[+]	DD Syngas, H_2O	150,000	159,200			
Methanol[+]	DD Syngas, H_2	210,000	16,200			
Oxygen/Nitrogen[+]	Air	150,000	10,000	4,040	3	
				8,902	5	Size factor of 0.7 assumed
Raw Syngas[+]	Coal, Steam, O_2	5,329,000	74,270			
SCOT Off-gas[+]	CLAUS Off-gas, Hydrogen, Air	10,100	2,200			
SNG[+]	DD Syngas, H_2	202,400	27,000			
Sulfur[+]	H_2O Stream, Air	13,536	1,046			
Sulfuric Acid[+]	S, Air, Water	500,000	22,100	5,190	4	
				5,560	3	
				5,090	7	Size factor of 0.7 assumed
				12,370	5	Size factor of 0.7 assumed
Urea[+]	NH_3, CO_2	140,000	13,270	8,640	4	
				7,720	3	
				12,200	5	Size factor of 0.7 assumed

[*]DD denotes dry desulfurized.

(Continued)

TABLE 2-III (Continued)

COMPARISON OF ALLEN/PAGE COST ESTIMATES WITH REPORTED LITERATURE VALUES

Product(s)	Reactants	Production Rate, tons/yr	Capital Cost Estimates (1976, M$) Allen/Page	Others	Ref	Comments
Acetaldehyde	Ethylene & Oxygen	50,000	3,870	6,286	3	
Acetic Acid	Acetaldehyde & Air	100,000	7,769			
Acetic Anhydride	Acetaldehyde & Oxygen	100,000	3,326			
Acrylic Acid	Propylene & Air	50,000	27,230	11,380	6	250 yen/$ assumed
Acrylonitrile	Propylene, Ammonia & Air	100,000	30,553			
Ammonia	Natural Gas, Steam & Air	500,000	47,993	28,740	3	
				32,840	4	
				82,800	5	Size factor of 0.7 assumed
				21,370	7	Size factor of 0.7 assumed
Aniline	Nitrobenzene & Hydrogen	20,000	1,464			
Butanol, sec-	n-Butene & Water	27,500	6,812	6,400	4	
				3,850	5	Size factor of 0.7 assumed
				7,650	6	
Carbon Monoxide	Coal, Steam & Air	400,000	54,800			
Choline Chloride	Ethylene Oxide, Trimethylamine & Hydrogen Chloride	5,000	415			

(Continued)

TABLE 2-III (Continued)

COMPARISON OF ALLEN/PAGE COST ESTIMATES WITH REPORTED LITERATURE VALUES

Product(s)	Reactants	Production Rate, tons/yr	Capital Cost Estimates (1976, M$) Allen/Page	Others	Ref	Comments
Chlorine/Caustic Soda	Brine	70,000 (+78,000 NaOH)	15,281	23,340	3	
				16,420	4	
				23,130	5	
				21,270	7	Size factor of 0.7 assumed
Cyclohexane	Benzene & Hydrogen	110,000	10,683	1,440	3	Size factor of 0.7 used
				5,530	4	
				2,225	5	Size factor of 0.7 assumed
				1,678	6	
				1,852	7	
Dimethyl Terephthalate	Terephthalic Acid & Methanol	110,000	2,401	13,810	6	
				13,720	7	
Ethanol	Ethylene & Water	75,000	10,800	6,735	3	
				89,890	4	
				10,980	5	Size factor of 0.7 assumed
Ethyl Ether	Ethanol	10,000	2,676	897	3	Size factor of 0.7 assumed
Ethylbenzene	Ethylene & Benzene	100,000	2,877	9,970	3	Size factor of 0.7 assumed
				5,025	5	Size factor of 0.7 assumed
Ethylene Dichloride	Ethylene & Chlorine	25,000	906	5,750	3	
Ethylene Diamine	Ethylene Dichloride & Ammonia	15,000	3,345			

(Continued)

TABLE 2-III (Continued)

COMPARISON OF ALLEN/PAGE COST ESTIMATES WITH REPORTED LITERATURE VALUES

			Capital Cost Estimates (1976, M$)			
Product(s)	Reactants	Production Rate, tons/yr	Allen/ Page	Others	Ref	Comments
Ethylene Oxide	Ethylene & Air	100,000	23,300	16,160	3	
				50,140	4	
				43,800	5	Size factor of 0.7 assumed
Ethyleneimine	Monoethanolamine, Caustic Soda & Sulfuric Acid	15,000	1,150			
Hydrogen Fluoride	Calcium Fluoride & Sulfuric Acid	30,000	2,613	7,585	3	Size factor of 0.7 assumed
				17,780	7	
Isoprene	Acetone, Hydrogen & Propylene	30,000	5,901			
Isopropanol	Propylene & Water	150,000	8,208	13,470	3	
				17,000	5	Size factor of 0.7 assumed
				14,650	6	Size factor of 0.7 assumed
Lactic Acid	Lactonitrile & Sulfuric Acid	5,000	284			
Maleic Anhydride	Benzene & Air	60,000	27,700	36,720	3	Size factor of 0.7 assumed
Methanol	Natural Gas, Air & Water	210,000	35,330	16,160	3	
				15,210	4	
				25,600	5	Size factor of 0.7 assumed
				22,190	7	Size factor of 0.7 assumed
Methylamine	Methanol & Ammonia	10,000	2,517			

(Continued)

TABLE 2-III (Continued)

COMPARISON OF ALLEN/PAGE COST ESTIMATES WITH REPORTED LITERATURE VALUES

Product(s)	Reactants	Production Rate, tons/yr	Capital Cost Estimates (1976, M$) Allen/ Page	Others	Ref	Comments
Methyl Chloride	Methanol & Hydrogen Chloride	10,000	1,330	898	3	
Monoethanolamine	Ethylene Oxide, Ammonia & Water	25,000	1,467	3,143	3	
Nitric Acid	Ammonia & Air	50,000	1,487	8,980	3	
				2,590	4	
				2,170	7	
Phenol (+ Acetone)	Cumene & Air	100,000	21,800	28,260	3	Size factor of 0.7 assumed
				14,330	7	Size factor of 0.7 assumed
Phosgene	Carbon Monoxide & Chlorine	50,000	834			
Phthalic Anhydride	o-Xylene & Air	50,000	8,701	9,160	4	
				13,520	5	Size factor of 0.7 assumed
Polyethylene (HD)	Ethylene	200,000	1,956	25,140	3	
				103,700	4	
				131,500	5	Size factor of 0.7 assumed
Polyethylene (LD)	Ethylene	100,000	4,579	90,800	5	Size factor of 0.7 assumed
Polyisoprene	Isoprene	50,000	1,185	13,100	3	Size factor of 0.74 used
Polypropylene	Propylene	150,000	3,569	121,000	4	
Polyvinyl Chloride	Vinyl Chloride	100,000	1,852	51,870	4	

(Continued)

TABLE 2-III (Concluded)

COMPARISON OF ALLEN/PAGE COST ESTIMATES WITH REPORTED LITERATURE VALUES

			Capital Cost Estimates (1976, M$)			
Product(s)	Reactants	Production Rate, tons/yr	Allen/ Page	Others	Ref	Comments
Styrene	Benzene & Ethylene	250,000	6,358	39,760 21,330	4 7	
Terephthalic Acid	p-Xylene & Air	110,000	4,051	17,000	6	
Tetrahydrofuran	Maleic Anhydride & Hydrogen	5,500	6,206	4,675	6	250 yen/$ assumed
Trichlorofluoro-methane	Hydrogen Fluoride & Carbon Tetra-chloride	25,000	2,782			
Vinyl Acetate	Ethylene, Acetic Acid & Oxygen	100,000	15,493	23,870 3,630	3 4	Size factor of 0.7 assumed
Vinyl Chloride	Ethylene Dichloride	100,000	1,891	3,590 15,560 11,570	3 4 5	

TABLE 2-IV

SUMMARY OF ALLEN/PAGE PARAMETERS

Product(s)	Reactants	Cap/Prodn Rate (lb/mole/ton)	N	EXP	FF	PF	FTMAX	FPMAX	FMMEAN	FLANG
Ammonia+	Nitrogen, Hydrogen	234.7	23	0.754	3.65	0.9205	1.11	1.29	1.06	4.8
Dry Desulfurized (DD) Syngas+	Raw Syngas	131.4	14	0.732	4.14	0.8646	1.02	1.02	1.00	4.8
Formaldehyde+	Methanol, Air	144.0	26	0.578	3.15	0.5075	1.10	1.00	1.50	4.8
Gasoline+	Methanol	202.3	31	0.597	2.94	0.3623	1.10	1.00	1.28	4.8
Hydrogen+	DD Syngas, Water	2657.0	33	0.616	3.58	0.8257	1.11	1.10	1.21	4.8
Methanol+	DD Syngas, Hydrogen	187.2	11	0.755	3.00	0.9166	1.13	1.29	1.23	4.8
Oxygen/Nitrogen+	Air	342.8	15	0.597	4.40	0.6742	1.14	1.00	1.06	4.8
Raw Syngas (from hard coal)+	Coal, Steam, Oxygen	152.5	28	0.657	3.04	0.5432	1.18	1.00	1.00	4.8
SCOT Off-Gas+	CLAUS Off-Gas, Hydrogen, Air	107.8	16	0.710	3.69	0.6950	1.07	1.01	1.14	4.8
SNG+	DD Syngas, Hydrogen	420.5	22	0.687	3.18	0.8257	1.08	1.10	1.00	4.8
Sulfur+	H_2S Stream, Air	246.0	11	0.656	3.00	0.6439	1.08	1.00	1.00	4.8
Sulfuric Acid+	Sulfur, Air, Water	196.6	21	0.696	2.86	0.5313	1.13	1.00	1.50	3.6
Urea+	Ammonia, CO_2	275.8	22	0.666	3.36	0.5984	1.06	1.25	1.28	3.6

(Continued)

TABLE 2-IV (Continued)

SUMMARY OF ALLEN/PAGE PARAMETERS

Product(s)	Reactants	Cap/Prodn Rate (lb/mole/ton)	N	EXP	FF	PF	FTMAX	FPMAX	FMMEAN	FLANG
Acetaldehyde	Ethylene, Oxygen	78.6	24	0.677	3.04	0.7992	1.06	1.01	1.28	4.77
Acetic Acid	Acetaldehyde, Air	68.9	34	0.710	3.03	0.7134	1.06	1.00	1.28	4.77
Acetic Anhydride	Acetaldehyde,Oxygen	81.7	16	0.702	3.19	0.5075	1.04	1.00	1.28	4.77
Acrylic Acid	Propylene, Air	780.0	36	0.645	3.31	0.6460	1.09	1.01	1.50	4.77
Acrylonitrile	Propylene,Ammonia,Air	550.0	44	0.630	3.98	0.7375	1.09	1.00	1.22	4.77
Ammonia	Natural Gas,Steam,Air	185.6	31	0.652	3.32	0.8780	1.12	1.25	1.10	4.77
Aniline	Nitrobenzene,Hydrogen	95.5	34	0.689	2.62	0.3899	1.08	1.00	1.00	4.77
Butanol, sec-	n-Butene, Water	549.1	36	0.659	2.69	0.3960	1.07	1.00	1.09	4.77
Carbon Monoxide	Coal,Steam,Air	260.0	32	0.739	2.91	0.5700	1.13	1.20	1.28	4.77
Caustic Soda/ Chlorine	Brine Solution	623.1	44	0.533	3.18	0.4393	1.05	1.00	1.27	4.77
Choline Chloride	Ethylene Oxide,Hydrogen Chloride, Trimethylamine	278.0	9	0.608	2.40	0.4519	1.04	1.10	1.15	4.77
Cyclohexane	Benzene,Hydrogen	178.5	28	0.671	2.82	0.8289	1.09	1.04	1.00	4.77
Dimethyl Terephthalate	Terephthalic Acid, Methanol	31.7	19	0.578	3.74	0.5864	1.08	1.01	1.28	4.77
Ethanol	Ethylene, Water	179.3	14	0.696	3.40	0.9075	1.09	1.40	1.50	4.77
Ethyl Ether	Ethanol	288.0	26	0.620	3.38	0.5460	1.06	1.00	1.28	4.77
Ethylbenzene	Ethylene, Benzene	40.1	16	0.659	3.38	0.8200	1.05	1.01	1.35	4.77

(Continued)

TABLE 2-IV (Continued)

SUMMARY OF ALLEN/PAGE PARAMETERS

Product(s)	Reactants	Cap/Prodn Rate (lb/mole/ton)	N	EXP	FF	PF	FTMAX	FPMAX	FMMEAN	FLANG
Ethylene Dichloride	Ethylene, Chlorine	45.2	20	0.674	2.60	0.6075	1.05	1.15	1.00	4.77
Ethylene Oxide	Ethylene, Air	250.3	40	0.726	3.40	0.7825	1.07	1.01	1.05	4.77
Ethylenediamine	Ethylene Dichloride, Ammonia	1047.3	18	0.669	1.61	0.3408	1.05	1.17	1.39	4.77
Ethyleneimine	Monoethanolamine, Sulfuric Acid Caustic Soda	406.0	9	0.572	2.67	0.3408	1.07	1.08	1.00	6.67
Hydrogen Fluoride	Calcium Fluoride, Sulfuric Acid	54.7	31	0.690	3.35	0.3946	1.05	1.40	1.33	4.77
Isoprene	Acetone, Hydrogen, Acetylene	110.7	71	0.634	3.00	0.4300	1.07	1.04	1.12	4.77
Isopropanol	Propylene, Water	70.5	27	0.713	2.78	0.6667	1.09	1.18	1.08	4.77
Lactic Acid	Lactonitrile, Sulfuric Acid	38.0	17	0.616	2.71	0.5400	1.08	1.00	1.50	4.00
Maleic Anhydride	Benzene, Air	2832.5	20	0.640	2.85	0.6075	1.08	1.00	1.28	4.77
Methanol	Natural Gas, Air, Water	157.6	25	0.788	2.72	0.8880	1.13	1.30	1.32	4.77
Methyl Chloride	Methanol, Hydrogen Chloride	831.0	11	0.547	2.46	0.5530	1.07	1.00	1.05	4.77
Methylamine	Methanol, Ammonia	139.0	34	0.684	3.62	0.8016	1.09	1.03	1.00	4.77

(Continued)

TABLE 2-IV (Continued)

SUMMARY OF ALLEN/PAGE PARAMETERS

Product(s)	Reactants	Cap/Prodn Rate (lb/mole/ton)	N	EXP	FF	PF	FTMAX	FPMAX	FMMEAN	FLANG
Monoethanolamine	Ethylene Oxide, Ammonia, Water	69.2	26	0.735	3.12	0.3921	1.05	1.00	1.28	4.77
Nitric Acid	Ammonia, Air	84.8	14	0.525	3.21	0.5790	1.14	1.00	1.28	4.00
Phenol	Cumene, Air	140.0	55	0.647	3.27	0.5530	1.07	1.17	1.50	4.77
Phosgene	Carbon Monoxide, Chlorine	40.4	14	0.681	2.00	0.7218	1.05	1.00	1.13	4.77
Phthalic Anhydride	o-Xylene, Air	3020.0	15	0.527	3.27	0.4742	1.12	1.00	1.00	4.77
Polyethylene (HD)	Ethylene	72.2	18	0.633	2.72	0.2297	1.04	1.03	1.00	4.77
Polyethylene (LD)	Ethylene	78.6	14	0.774	2.14	0.7220	1.08	1.24	1.09	6.67
Polyisoprene	Isoprene	32.0	36	0.498	2.05	0.2019	1.05	1.00	1.28	4.77
Polypropylene	Propylene	50.8	25	0.682	2.72	0.3675	1.05	1.01	1.28	4.77
Polyvinyl Chloride	Vinyl Chloride	33.7	24	0.392	2.54	0.2150	1.03	1.00	1.28	6.50
Styrene	Benzene, Ethylene	45.2	37	0.585	3.35	0.4940	1.10	1.00	1.00	4.77
Terephthalic Acid	p-Xylene, Air	289.4	17	0.534	2.71	0.5369	1.06	1.00	1.00	4.77

(Continued)

TABLE 2-IV (Concluded)

SUMMARY OF ALLEN/PAGE PARAMETERS

Product(s)	Reactants	Cap/Prodn Rate (lb/mole/ton)	N	EXP	FF	PF	FTMAX	FPMAX	FMMEAN	FLANG
Tetrahydrofuran	Maleic Anhydride, Hydrogen	198.0	20	0.776	3.20	0.5575	1.08	1.24	1.00	4.77
Trichlorofluoromethane	Hydrogen Fluoride, Carbon Tetrachloride	121.2	24	0.684	2.83	0.5908	1.05	1.15	1.25	4.77
Vinyl Acetate	Ethylene, Acetic Acid, Oxygen	151.2	34	0.654	3.29	0.8016	1.06	1.00	1.48	4.77
Vinyl Chloride	Ethylene Dichloride	33.4	13	0.668	2.85	0.8537	1.08	1.01	1.28	4.77

selection and land use was obtained from a variety of sources and handbooks eg 11-52/. The available data was filed and catalogued for easy and rapid accessing.

2.3 Task II - Development of Criteria for Total Systems Integration

Before candidate processes for fully-integrated co-siting complexes can be selected, matched and coupled to initiate system integration, it is necessary that screening, selection and grouping criteria be developed. Specifically, sets of desired advantages to be sought by way of systems integration, based on synergistic co-siting methodology, and associated practical, realistic constraints, which will influence the design and functioning of such systems, must be formulated. This was accomplished by a very careful, detailed analysis of the information compiled on Task I relating to federal regulations, controls, desired objectives and planning for resources conservation, industrial development, etc.. Although the relative extent of impact of each such desired objective or constraint was not assessed at this point in the program (reserved for Tasks IV and V), general categories were identified as a basis for evaluating the attractiveness of matched process groupings on Task III. The reason for this procedure is explained in more detail in the discussion material of Sections 2.4 and 2.5 for Tasks III and IV, respectively.

Examples of factors considered in formulating the required systems-integration criteria include:

- Regulatory controls and limits which serve as the basis both for desired goals of complexing and constraints upon the design of complexes.

- Trends in the availability and cost of raw materials and feedstocks.

- Trends in the market growth of various chemical commodities, and industrial-expansion planning to capitalize on those for which viability aspects are particularly attractive.

- Input-output features of processes which can provide flexibility for future expansion, particularly through modular design approaches in integrated-system development.

- Requirements for feedstock redundancy (e.g., series-parallel and networking) to maximize reliability of crucial supplies and minimize interdependency problems.

2.4 Task III - Coupling-Matching Analysis

The principal technology methodology associated with this task involved searching for input-output matches, among a large field of candidate processes, to form synergistic couplings of two or more of these processes. No attempt was made on this task to optimize these couplings or develop complete complexes; that was accomplished on Task IV using selected couplings from the "reservoir" of such couplings developed on Task III. The basis for retention of couplings in this reservoir was the identifiable potential of each coupling to satisfy one or more of the criteria developed on Task II. Retained couplings were then characterized as to their coupling functions, or matching interfaces which provided the basis for their selection and retention. These interfaces are summarized in Figure 2-2. The interaction among typical shared interfaces in synergistic arrangements is illustrated

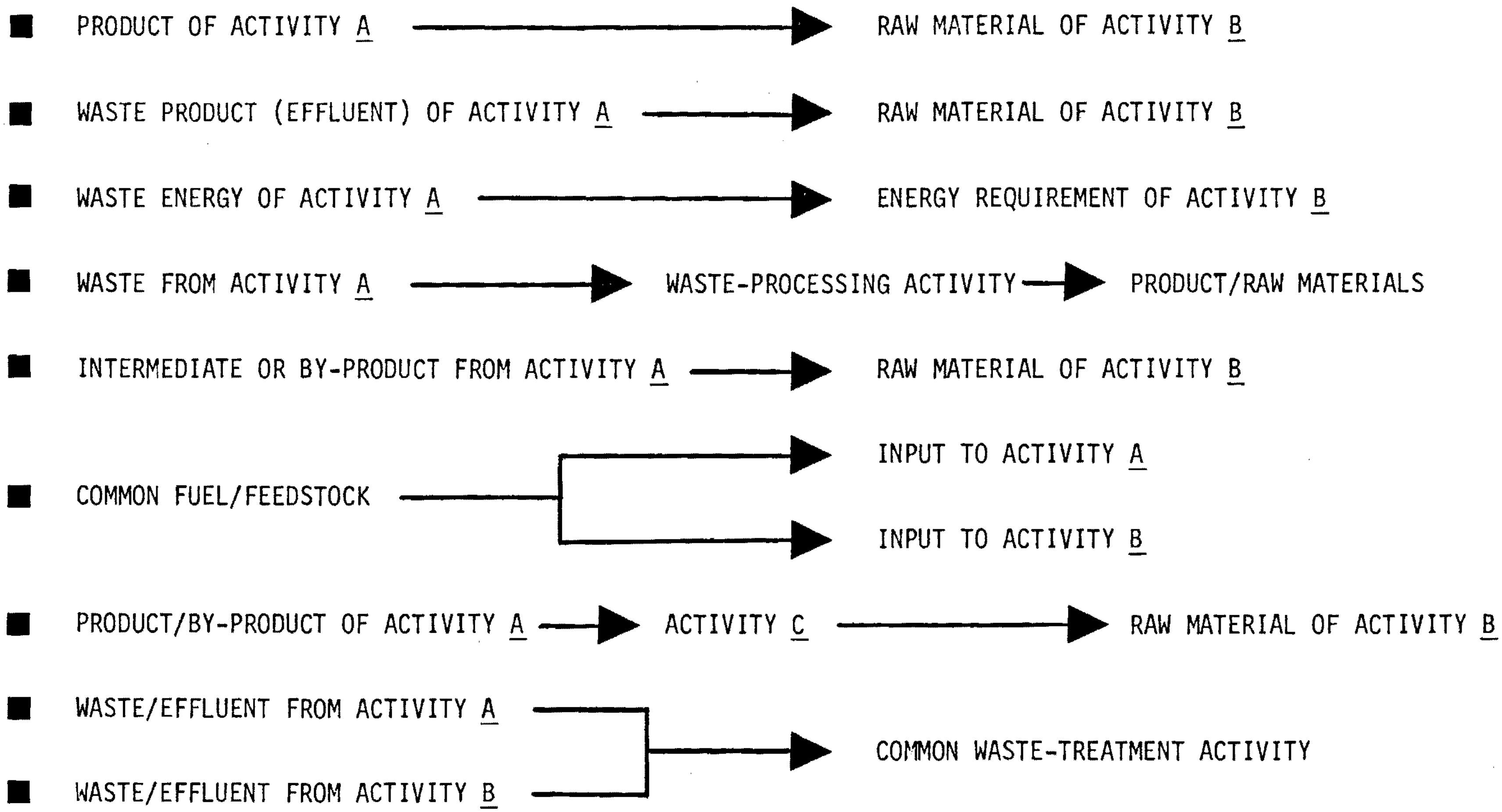

Figure 2-2. Principal Coupling Interfaces for the Design of Synergistic Complexes

in Figure 2-3. The resulting storage file forms the easily-accessible reservoir of couplings from which fully-integrated synergistic co-siting systems designs can be formulated on Task IV.

Automated searching for input-output matches is possible for all those candidate processes in the computerized data base (compiled on Task I), utilizing the material-balance interfaces that are listed for each. We have determined that, in general, this includes most of the practical matching-coupling possibilities. However, two additional potentially important classes of synergistic interfaces were considered: (1) process-internal points where conventional steps, that do not suggest apparent coupling benefits, are replaceable by feasible, practical alternative steps that do suggest such benefits; and (2) process-internal or -external points at which synergistic coupling between two processes could be highly probable when a third "missing link" process (or simply one or more additional, unconventional but practical steps) are identified and included. These latter classes generally require manual analysis of flow sheets, which is a very time-consuming procedure. However, our project team identified a few labor-saving generalizations that help in such a manual search effort. These are based principally on experience with process control and process systems-integration studies which has developed an intuition for flow sheet points, components and design practices that are prime targets for design improvements, the fusion of processes, etc. (e.g., heat exchangers, fuel-use points, and component- or phase-separation points). For completeness, a total-systems-integration analysis must include the consideration of as many sources of synergistic benefit as are reasonably possible. Therefore, our coupling-matching analysis consists of both automated and manual searching procedures.

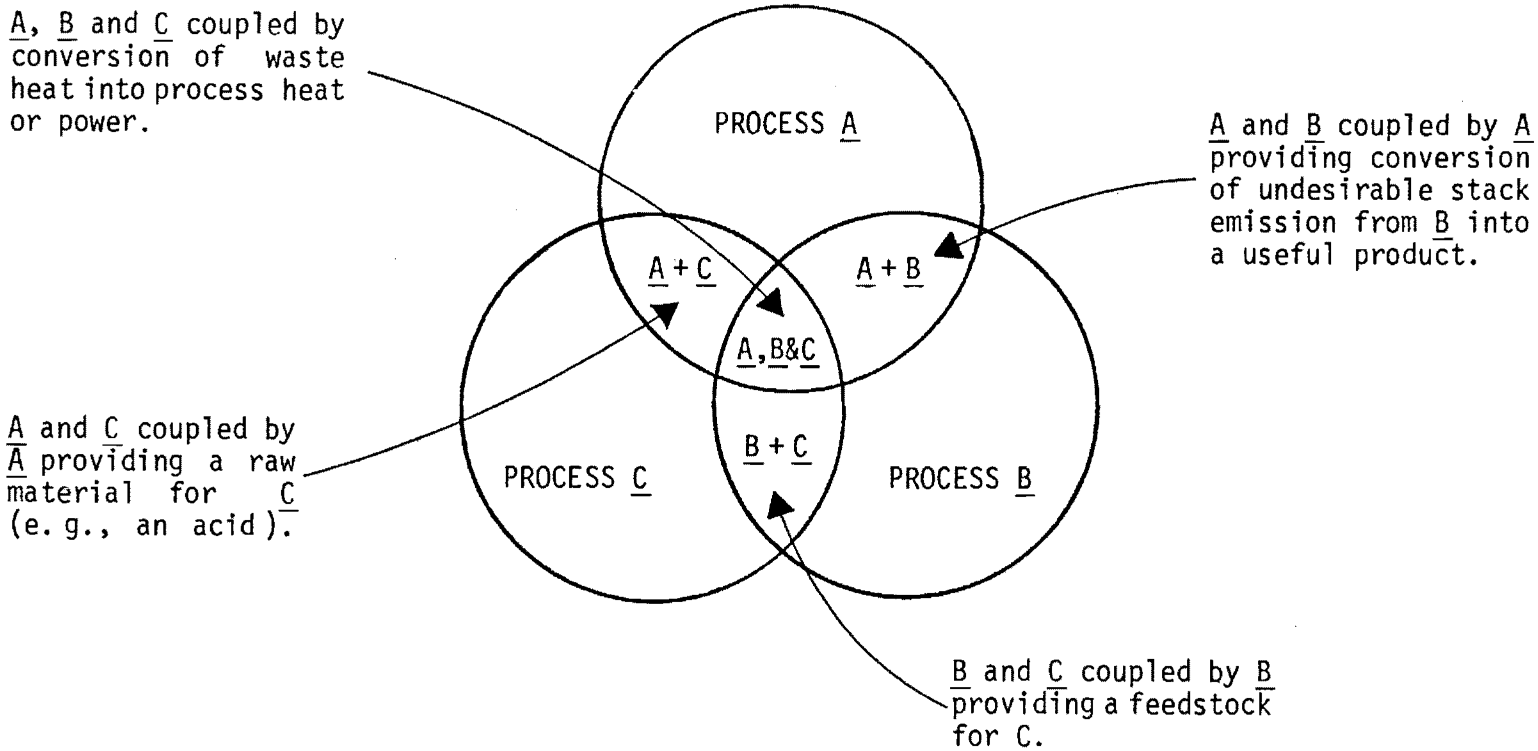

Figure 2-3. Interaction Among Typical Shared Interfaces

The automated search methodology developed by the project team utilized the pertinent data-base file for commodities (flow sheet information), described for Task I, together with matrix entries to perform material balance calculations about individual processes or plants as well as two or more coupled processes. These calculations characterized the potential for synergistic coupling among the field of processes for which adequate input-output data have been compiled in the data base. This methodology has been described in recent papers authored by the project team 53,54/.

The product of this task is a reservoir of coded and characterized candidate couplings for use in formulating and specifying the design requirements of fully-integrated, synergistically co-sited systems. These results were used as inputs to Tasks IV and V.

2.5 Task IV - Systems Integration Analysis

This task involved the combination of the essential results from Tasks I, II and III for the formulation and specification of key design features of integrated, synergistically co-sited industrial-complex systems. As in the case of Task III, the methodology employed involves both manual and computerized procedures for the development of these integrated-systems design concepts. The development, or formulation, procedure is based upon an extension of our previously developed methodology for combining industrial groupings to form synergistic co-siting complexes. In addition, two new procedural techniques were explored. These were: (1) modularization of the building-up procedure by which the complexing design concepts are structured and refined; and (2) synergistic interface visualization, an adaptation of computer-aided graphic design.

One of the most valuable techniques in our previously developed methodology 53,54/ involves the use of adjacency and reachability matrices to guide the search for couplings (from Task III) that can be combined in "building-block" fashion as the basis for systems integration. Briefly, this procedure uses input-output information from the data base, and is based upon principles of graph theory and its primary mathematical tool, Boolean algebra. This procedure produces lists of chemical commodities which are related by various connection orders (i.e., first, second, third, etc.) with the selected raw materials. The significance of these connection orders is demonstrated in the example presented in Section 3.3.

Our concept of modularization involved the integration of candidate couplings into progressively more sophisticated but feasible and practically-achievable functional modules. Each modular step is, of course, based upon satisfying several of the systems-integration criteria prescribed in Task II, and uses combinations of candidate couplings that were provided by Task III. A module is initially examined for completeness, preliminary economic attractiveness and expansion potential to greater synergistic sophistication. If the module is not complete (i.e., not a good industrial operation according to criteria for technical viability), refinements must be sought (such as additional or modified couplings) to provide completeness. If this cannot be done, the module is not considered further (at least until all other modules have been similarly examined). The module receives similar treatment, simultaneously, with respect to its economic attractiveness potential. Expansion potential is assessed merely to determine the flexibility for stage-wise or time-phased integration to include more couplings without sacrificing technical or economic viability prospects; a module is not rejected from further consideration if this flexibility is not apparent. By this iterative procedure, which progresses from module to module, among the field of modular concepts, design features for fully-integrated, synergistically co-sited complexes can be specified based upon the more attractive modules (taken singly or in combinations).

The synergistic-interface visualization technique is still conceptual, but it appears to have significant promise and an important role to play in our systems-integration methodology. Briefly, it involves the use of computerized graphic displays (i.e., on a CRT terminal, with hard-copy option) of stored flow sheet information for the candidate couplings from Task III, or grouping modules from the identification of process-internal or -external coupling points, material or energy streams, etc., which might serve as synergistic interfaces for systems integration. When considered in combination with the adjacency and reachability technique and the modularization procedure, the synergistic-interface visualization technique appears to be a very attractive approach to systematizing the manual search and design specification processes. This concept was explored further during the early part of the effort on Task IV. It can be developed into a functional tool for future work if it continues to appear worth the developmental effort. However, for this present project, the required cost of the graphic-display computer terminal and associated software was too expensive.

Once the design concept for each complex was formulated to the extent that the principal processes that will comprise the complex have been identified, together with the synergistic interaces through which these processes will be coupled, complete systems-design and cost analyses were performed for the complex.

By their very nature, process analysis and cost-estimation calculations have always required a large amount of tedious computation effort. Traditionally, these calculations have been performed via manual and/or graphical methods, and these methods still prevail when no other alternatives are readily available. There have been many developments in this area in recent years, enlisting the aid of digital computers in the implementation of the extensive calculations that are involved in these analyses. Many major companies and academic institutions have developed process simulators and cost estimation packages of varying levels of sophistication.

Early in the project, the various manual and available computerized process simulation and cost-estimation methods were thoroughly investigated and discussed with our Overview Committee. For various reasons, including cost compared to project funds available as well as the overall objectives of the study, it was decided to use the Allen/Page method 10/. This method requires detailed process and equipment specification and is thus useful in estimating the costs of modified or unconventional processes for which historical data are either unavailable or not applicable. Thus, it is ideally suited for estimating the costs of systems-integrated co-sited complexes where interfacing (shared utilities, common waste cleanup unit, energy coupling, common feedstock etc.) occurs between and among the various plants comprising the complex.

2.6 Task V - Tradeoff and Cost-Benefit Analysis

The careful, rigorous screening process, and the associated requirement that certain key selection criteria be met, assures the potential technical and economic viability of co-sited systems. Furthermore, the very foundation for the formulation of these systems is the delivery of manifold economic and social benefits (such as those shown in Table 1-I). However, optimism and enthusiasm associated with anticipated widespread advantages suggested by synergistic co-siting must not displace concern for real-world constraints. There are tradeoff factors to be considered in any realistic evaluation of a technological innovation.

These tradeoff factors can provide the rationale for arguments against a new alternative approach or unconventional concept, and hence derive barriers to acceptability and implementation of those innovations. Therefore, as many of these factors as possible must be anticipated and effectively assessed for significance before implementation is recommended. Examples of the types of tradeoff factors that must be considered are presented in Table 2-V. Through a combination of tradeoff analysis and cost-benefit analysis, these and other identifiable factors can be assessed for significance, as appropriate.

Tradeoff analysis provides a first-cut qualitative assessment of potential problem areas, and aids in identifying key tradeoff factors that must be analyzed in depth. For a selected system, it involves the formulation of a list of relevant factors, similar to those listed in Table 2-V, which might be important in the functions and operations of both the complex and the alternative conventional industrial activities (e.g., single units or partially-integrated units which produce all the same commodities produced by

TABLE 2-V

EXAMPLE TRADEOFF FACTORS THAT AFFECT THE ATTRACTIVENESS OF INDUSTRIAL COMPLEXES

- Carryover fire/explosion vulnerability ("domino effect")
- Larger storage pools of hazardous chemicals
- National defense vulnerability
- Reliability interdependency among industrial units
- Effect on protection of proprietary processes
- Ownership/management structure
- Reliability of raw material and feedstock availability
- Regional and community impact (two-way)
- Availability of suitable land for all units
- Availability of fuels and energy for all units
- Availability of transportation networks
- Proximity to markets and raw materials for all units

the complex). It is usually convenient, for complicated systems, to organize the information in tabular fashion to facilitate the qualitative comparisons, as shown in the simplified example of Table 2-VI. This example also illustrates the assignment of "severity scores," based on value judgments, for each category of tradeoff factor among the alternative approaches. For the value judgments to be effective, they must be realistically indicative of the attitudes of decision-makers who would have key responsibility for crucial decisions in a given tradeoff-factor category. These can be determined quite adequately from historical decisions (case studies), and the analysis of regional factors (Task 2-VII). It should be noted that at this point in the analysis, quantitative cost comparisons, per se, are not used as factors. These are used extensively in the cost-benefit analysis which is the next step in the evaluation of a given system design. The tradeoff analysis provides valuable guidelines for the construction of the cost-benefit model, principally by targeting the key comparison parameters and cost or benefit elements to be included in that model.

Cost benefit analysis is a systematic approach to project evaluation that is designed to consider external costs and benefits in determining the extent to which benefits of a proposed innovation outweigh (or are outweighed by) the attendant costs of innovation. It attempts to quantify externalities such as air-pollution damage, cultural impacts or other factors similar to those listed in Table 2-V. Many of these factors cannot be quantified, but must be treated as subjective factors in the manner described above for tradeoff analysis, when interpreting the results of cost-benefit analysis. In our study, the analysis was structured between

TABLE 2-VI

EXAMPLE OF TABULAR ORGANIZATION FOR COMPARISON OF SIGNIFICANCE OF TRADEOFF FACTORS AMONG OPTIONS

	Factor - Severity for Comparative Options or Alternatives			
Tradeoff Factors	Option I ----	Option II ----	Option III -----	Etc.
1. Fire/Explosion Vulnerability	A	B	A	
2. Reliability of Raw Materials Availability	B	A	B	
3. Environmental Impact on Community	A	C	B	
4. By-Product/ Waste Overburden	A	B	C	
.				
.				
.				
etc.				

Factor-Severeity Code:

A - negligible problem; or ready solution at modest cost.

B - moderately severe; or moderately costly solution.

C - extremely severe (threatening viability); or prohibitively costly solution.

two course of action: the conventional approach to manufacturing a selected set of commodities (the baseline scenario), and the synergistically co-sited system alternative (the alternative scenario).

In performing this type of analysis, the principal question that must be resolved initially is: costs and benefits to whom? The answer to this question depends on the point of view of the decision-maker. Thus, the decision context of the problem must be specified in order for the cost-benefit analysis to have meaning and usefulness.

In addition to providing a realistic evaluation of the potential acceptability of a candidate complex, this type of analysis also identifies potential gaps between the attractiveness of the innovation to society and its acceptability to industrial planners (or investors) under present circumstances. For example, if the analysis shows very significant benefit potential for national goals, but shows marginal or poor cost-benefit relationship from industry's viewpoint, this suggests a role for policy changes, government incentives, subsidies in research and development, etc., to bring cost-benefit advantages for both groups of decision-makers.

Another important use of this type of analysis is the identification of any changes in the scenario for an innovation scheme (candidate co-sited complex) that could improve its relative attractiveness from the cost-benefit aspects involved. Option paths might be identified that show much better attractiveness and acceptability potential if, for example, full integration took place not at the beginning of implementation but in a time-phased series of integration steps.

2.7 Task VI - Regional Application Analysis

Efforts on this task sought to elucidate region-specific factors that appear to have influence, to some extent, on individual and complexed industrial-plant siting. Data-base information compiled on Task I was analyzed to characterize such factors as geographical, policy and regulatory, market, supply and transportation constraints, as well as others, which combine to affect siting choices of industrial planners.

Typical site-selection factors, based on regional considerations, are summarized in Table 2-VII. Before complexing options can be finally selected for a region, regional application analyses will be necessary to provide adequate consideration of these factors, on a region-specific basis. This step will require extensive cooperative efforts with regional industrial planners and will be taken only when serious in-depth applicational projects have been initiated for specific prototype locations.

2.8 Task VII - Formulation of Conclusions and Recommendations

This task principally consisted of reviewing essential results of Tasks IV, V, VI and VIII, assessing the overall significance of the findings that derived from efforts on these tasks, and compiling these into meaningful conclusions and recommendations that facilitate the use of program results.

2.9 Task VIII - Initiation of Utilization Plan

A vigorous, effectual time-phased activity of identifying and communicating with user groups was developed and implemented. Specific activities have included two meetings of an Overview Committee (see Appendix B for roster and minutes); communications with federal, state, and local agencies involved in industrial planning and development; participation in pertinent

TABLE 2-VII

TYPICAL SITE-SELECTION FACTORS

Costs

- Rapid escalation and substantial regional variation of construction and land costs.
- Higher insurance for a centralized facility due to higher concentration of risk.
- Projections for production costs (raw materials, utilities, transportation, etc.) needed to ensure lowest unit cost per unit of output over the lifetime of the facility.

Utilities

- Cost, supply and reliability of natural gas, oil, etc. need to be determined.
- An alternate fuel supply should be identified.

Environment

- Air and water pollution standards and guidelines in each region must be carefully evaluated.

Labor Force

- Sufficient supply of skilled labor required.
- Ratio of professional to hourly workers needs to be calculated as this will have a direct effect on the type of services the community must provide.
- Hours of operation must be decided because the labor supply varies according to the work coverage (seasonal, part-time, 5-day/2 shifts, 5-day/3 shifts, or 7-day).

Transportation

- To minimize cost with maximum service, decisions needed on whether industry is a heavy user of rail, raw-material or market-oriented, and whether containerization and piggyback is possible.
- Consideration must also be given to delivery time of products, shipment size, probability of loss and damage, predictability of arrive time, etc.

Community

- Consideration of crucial factors such as community size, pollution, crime, congestion, ease of transportation, labor cost, cost of living, tax rate structure, attitude toward newcomers, and services.

national meetings and conferences; publication and presentation of several project papers 53-56/; radio presentation of co-siting concepts; and visits with university professors in England and Scotland who are working in related areas.

SECTION 3.0. DEMONSTRATION OF METHODOLOGY

3.1 Introduction

Previously developed methodology has been used to demonstrate that significant reductions in capital investments are achievable by manufacturing industrial chemicals in a co-sited mode 1,2,56/. These reductions resulted mainly from the assumption that the production facility for a given chemical was a "black box" for which historical cost data was available. While this assumption allowed the benefits of economics of scale, it precluded any benefits which might have resulted from centralization of those processing steps in the black-box grouping which were common to the isolated production facilities.

In order to obtain more realistic economic evaluations of co-sited complexes, it was necessary to develop methodology which discarded the black-box assumption. In the event that certain processing steps in a process flowsheet are centralized, historical cost data are no longer valid (i.e., the new grouping is no longer "conventional") for purposes of cost analyses. The Allen/Page technique, as discussed in Sections 2.2 and 2.5, was used to estimate the costs of modified or unconventional process flowsheets for which historical cost data are either unavailable or not applicable.

The use and key aspects of the methodology developed will be illustrated through the following example.

3.2 Systems-Integration Analyses of Coal-Based Syngas Complexes

Gas mixtures containing CO, H_2, and N_2 in various ratios are used as feedstocks to produce a number of different chemical commodities including gaseous and liquid fuels. These mixtures, with the ratio of the components suitably adjusted, are called synthesis gases. Table 3-1 shows the volume ratios of the components required to produce various synthesis gases.

TABLE 3-I

VOLUME RATIOS IN SYNTHESIS GASES

Commodity or Process	H_2	CO	N_2
Ammonia	3	0	1
Methanol	2	1	0
Fisher-Tropsch (synthol)	2	1	0
Oxo (higher alcohols)	1	1	0
SNG	3	1	0

By reacting steam and air (or oxygen) with carbon in various forms - coal, biomass, municipal waste, etc. - a basic gas mixture called raw syngas is produced which can be used to make each of the synthesis gases listed in Table 3-1, as well as others. In view of the present world situation, the economic production and use of raw syngas is vital to our national economy and security.

For these reasons, 1979 analyses of complexes producing various commodities from raw syngas produced from coal have been chosen as examples to illustrate our methodology. The first step in analyzing a complex is to choose a core or core of industries. The choice of coal as a raw material satisfies this step.

The next procedural step in our methodology is a computerized or manual search for chemical commodities, in the data base, which are synergistic with coal. Since we have already decided on syngas-based complexes, the following synergistic commodities were chosen manually: ammonia, methanol, substitute natural gas (SNG), formaldehyde, gasoline, sulphur and sulfuric acid.

Next, realistic merchant production capacities for each of these products were selected. These are (in tons/yr)

Ammonia	: 100,000	Gasoline	: 200,000
Formaldehyde	: 20,000	SNG	: 100,000
Methanol	: 100,000	Sulfur	: 10,000
		Sulfuric Acid	: 100,000

Economic analyses were performed for individual or isolated plants manufacturing these products. The results of these analyses are shown in Table 3-II under the column heading "Isolated Operations." These costs include supporting plants as required.

The first levels of co-siting (C_1 and C_2) are represented schematically in Figures 3-1 and 3-2. In Complex C_1, three coal derivatives (ammonia, formaldehyde and methanol) are produced. Four coal derivatives (gasoline, SNG, sulfur and sulfuric acid) are produced in Complex C_2. The results of economic analyses for these two complexes are shown in Table 3-II under the column heading "First Level of Co-Siting." A significant (20.4 percent) reduction in the total capital investment, from 642.9 to 512.0 million dollars is observed here. This decrease results from several factors - a larger co-sited gasification plant, a larger co-sited moisture and acid-

TABLE 3-II

1979 CAPITAL COST COMPARISONS BETWEEN ISOLATED OPERATIONS AND VARIOUS CO-SITING LEVELS

Product	Isolated Operations			First Level of Co-Siting		Second Level of Co-Siting
	Capacity (tons/yr)	Cost* (MM$)		Cost* (MM$)		Cost* (MM$)
Ammonia	100,000	105.6				
Formaldehyde	20,000	34.8	C_1 →	165.3		
Methanol	100,000	76.8				
					C_{12} →	434.2
Gasoline	200,000	243.6				
SNG	100,000	148.6	C_2 →	346.7		
Sulfur	10,000	6.1				
Sulfuric Acid	100,000	27.4				
		642.9		512.0		434.2
(Savings in MM$ over Isolated Operations)		(0)		(130.9)		(208.7)
(Percent Savings over Isolated Operations)		(0)		(20.4)		(32.5)

*Capital cost only. Not included are off-site facilities, land costs, and utilities.

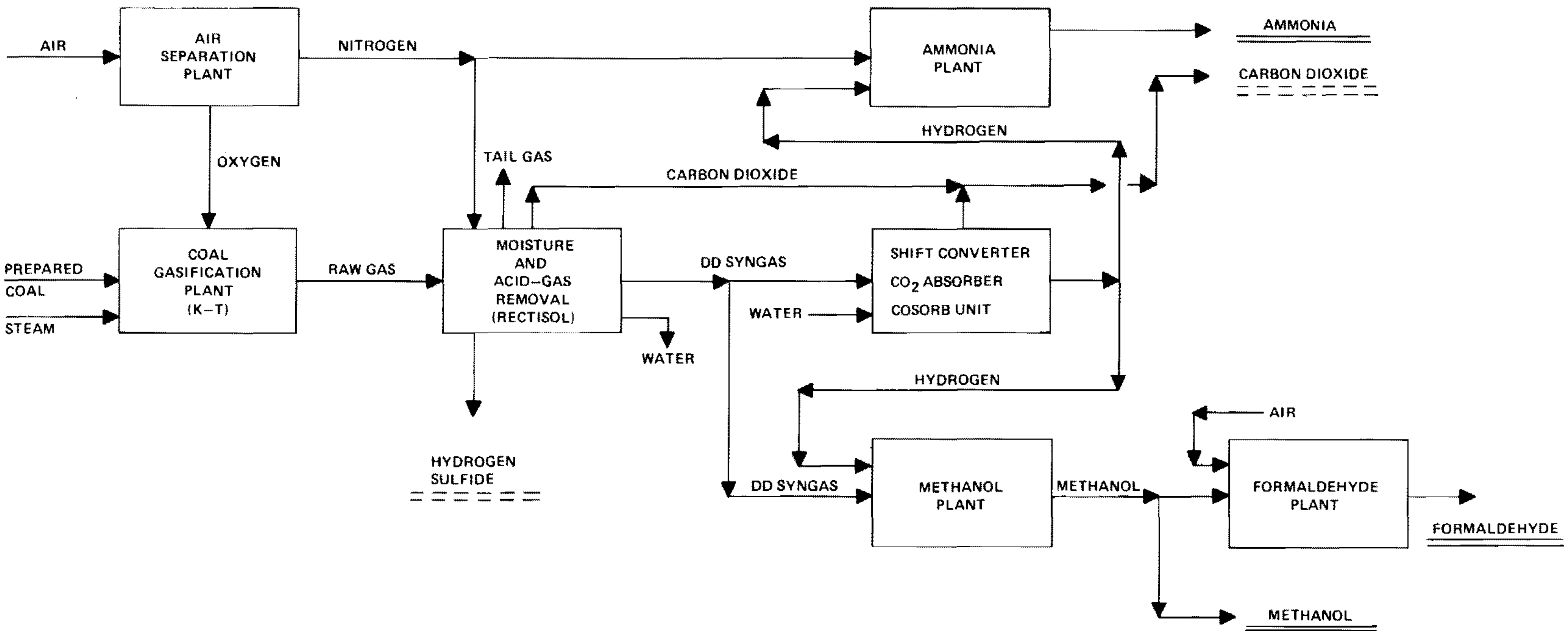

Figure 3–1. First Level of Co-Siting of Plants Producing Three Coal Derivatives, Complex C_1

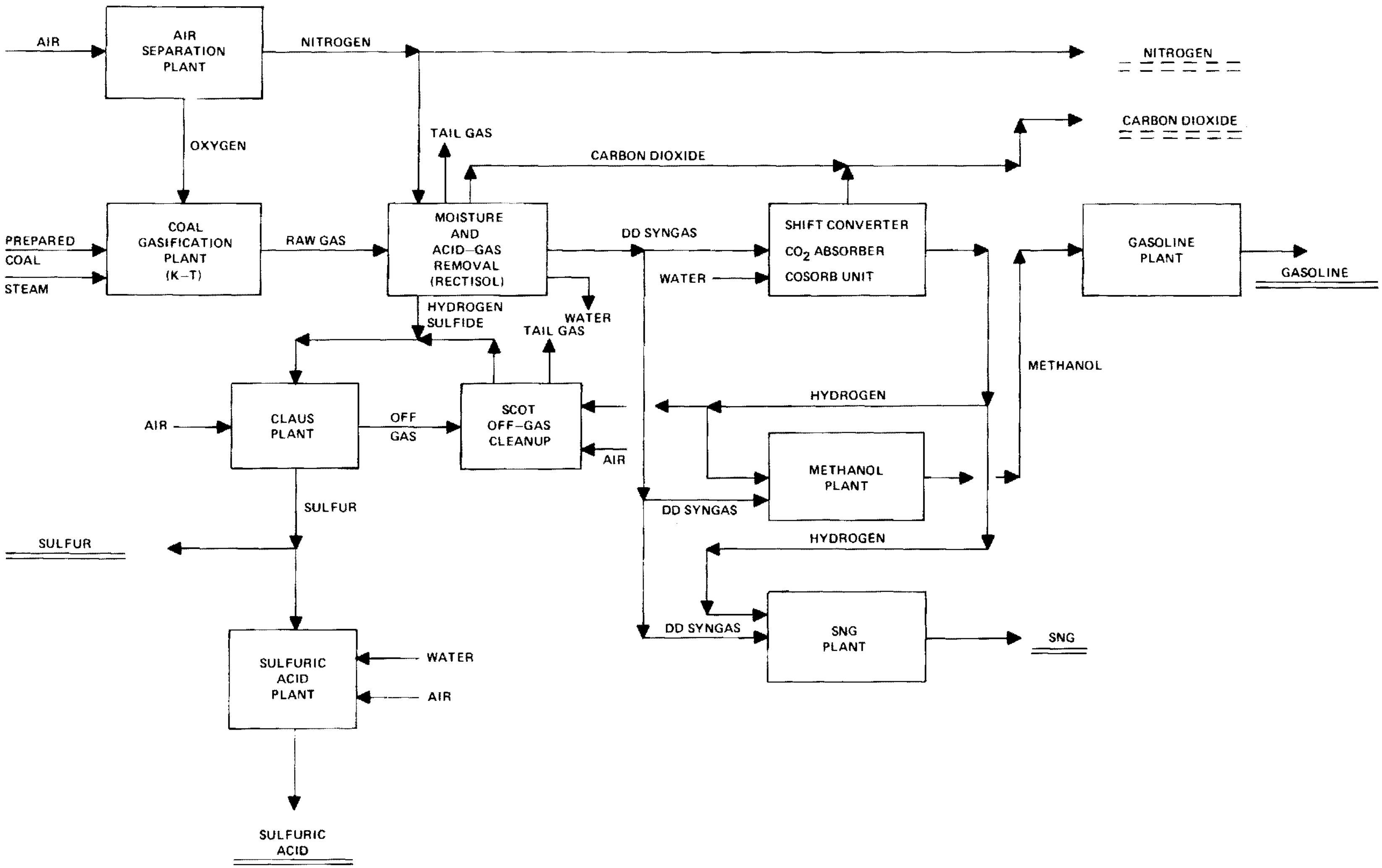

Figure 3–2. First Level of Co-Siting of Plants Producing Four Coal Derivatives, Complex C_2

gas removal plant, larger hydrogen producing plants, a larger methanol plant which produces an immediate as well as a final product, and interfacing connections between some of the processes.

The second level of co-siting (C_{12}) is represented schematically in Figure 3-3. All seven of the coal derivatives are produced in this complex. The results of the economic analyses for this complex also are given in Table 3-II under the heading "Second Level of Co-Siting." For this second level of co-siting, there is a further reduction (15.2 percent) in the total capital investment, from 512.0 to 434.2 million dollars. The reasons for this reduction are essentially the same as those for the similar decrease resulting from the first levels of co-siting as well as increased plant interfacing. Note also in this second level of co-siting that methanol serves as an intermediate product for the manufacture of both formaldehyde and gasoline as well as a final product.

These analyses were performed by means of a user-interactive computer program and the computer printout is shown in Appendix C, Section C.2.2. Note that since manual means were used to determine the synergistic couplings, steps 6, 7, and 8 were bypassed. This computer program is explained in detail in Appendix C, Sections C.1 and C.2.1. The next example illustrates the use of computer-determined couplings using historical cost data.

3.3 Second Example: Demonstration of Sensitivity Analysis Methodology

In our previous study for the Appalachian Regional Commission 1,2/, co-sited complexes were selected to utilize raw materials that are abundant in the northwestern portion of the State of Georgia. Based on a review of the mineral resources abundant in this region, coal was selected as the raw

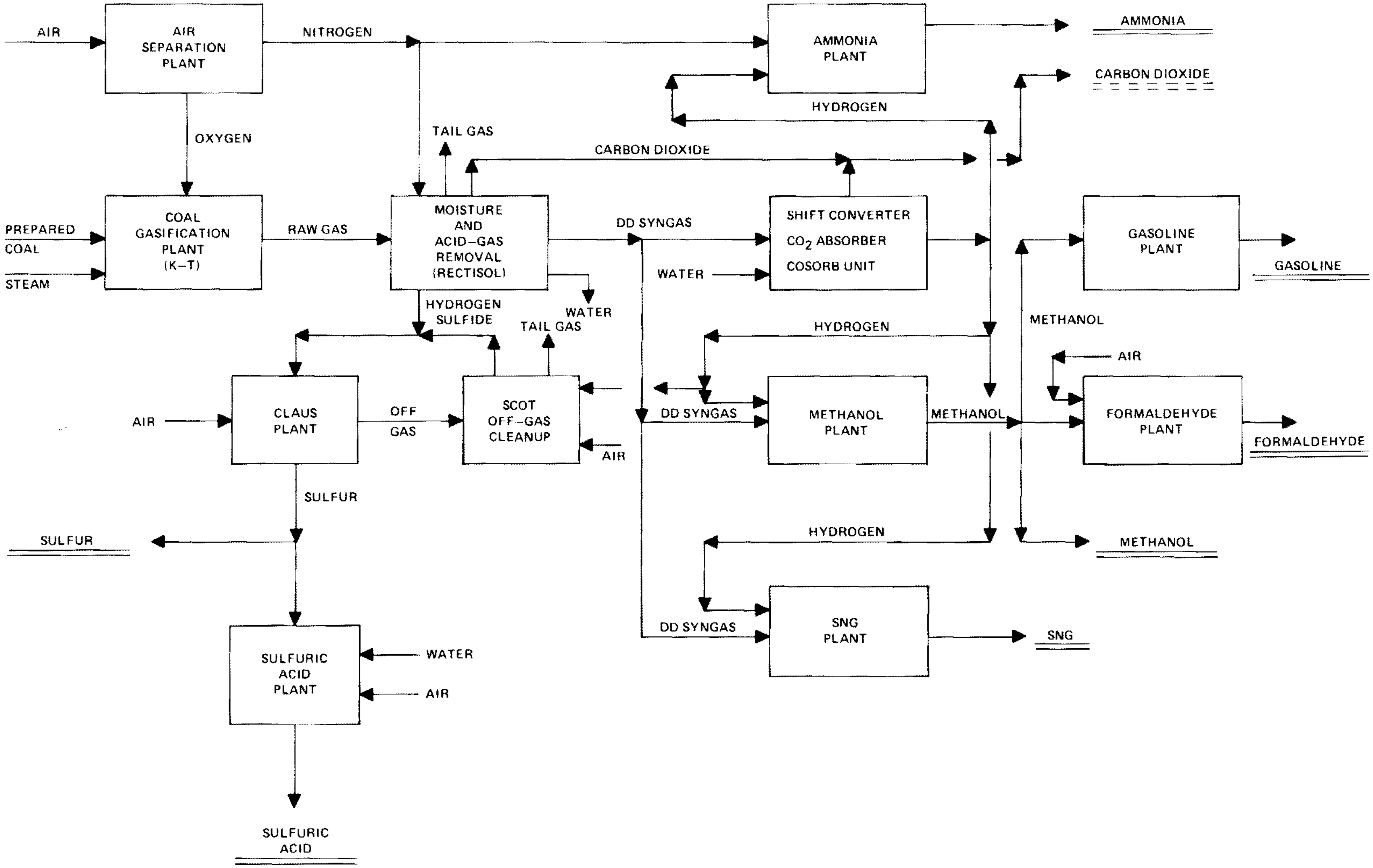

Figure 3–3. Second Level of Co-Siting of Plants Producing Seven Coal Derivatives, Complex C_{12}

material basis for co-sited complexes for this region. The economic analyses of two levels of co-siting were reported as part of the results of that study and are summarized below (with costs updated to 1978) to illustrate our previously developed methodology, our computerized matching techniques and to provide the background data necessary for the sensitivity analysis performed for these complexes on the present study.

The initial procedural step was a computerized search for chemical commodities, in the data base, which would be synergistic with coal. This procedure produces lists of chemical commodities which are related by various connection orders (i.e., first, second, third, etc. as explained in Appendix C, Section C.1) with the selected raw materials. Summaries of only the first-, second-, and third-order connections exhibited by coal with the other chemical commodities in the data base are given in Table 3-III. The first-order connections require no explanation. The second-order connections exhibited with methanol and phosgene occur through carbon monoxide, while the second-order connection with calcium carbide is through coke. The third-order connection exhibited with formaldehyde is through carbon monoxide and then methanol. Similarly, the third-order connection with acetylene is through coke and then calcium carbide.

Proceeding from the results of this search, candidate plants and complexes for the production of coal derivatives were analyzed. The following seven products were selected: coke, methanol, formaldehyde, calcium carbide, phosgene, acetylene and isoprene. Merchant production capacities for each of these products were then selected, and individual or isolated plants for manufacturing these products were analyzed. The results

TABLE 3-III

CHEMICAL COMMODITIES WITH WHICH COAL EXHIBITS CONNECTION ORDERS

A. First-Order Connections with:	
Carbon monoxide	
Coke	
Calcium oxide	
B. Second-Order Connections with:	
Methanol	Hydrogen
Carbon dioxide	Calcium carbonate
Sulfuric acid	Calcium carbide
Ammonium sulfate	Phosgene
C. Third-Order Connections with:	
Ammonia	Chlorine
Cyclohexane	Ethylene oxide
Formaldehyde	Maleic anhydride
Methyl chloride	Tetrahydrofuran
Urea	Sodium chlorate
Melamine	Acetylene
Ammonium chloride	Ethyl ether
Methyl methacrylate	Sulfur
Isoprene	

of these economic analyses, in terms of estimated capital costs associated with the manufacture of each of these products are summarized in Table 3-IV under the column heading "Isolated Operations." These costs include supporting plants such as carbon monoxide, lime, chlorine, and sulfuric acid plants as required.

The first levels of co-siting (C_3 and C_4) are represented schematically in Figures 3-4 and 3-5. In complex C_3, three coal derivatives (coke, methanol and formaldehyde) are produced. Four coal derivatives (calcium carbide, phosgene, acetylene and isoprene) are produced in complex C_4. The results of comparable economic analyses for these two complexes are shown in Table 3-IV under the column heading "First Level of Co-Siting." A significant reduction (12.7 percent) in the total capital investment, from 498.5 to 435.2 million dollars is observed here. This decrease results from several factors - a larger co-sited carbon monoxide plant and also larger co-sited plants for the manufacture of materials which serve as both intermediate and final products, such as methanol, calcium carbide and acetylene.

The second level of co-siting (C_7) is represented schematically in Figure 3-6. All seven of the coal derivatives are produced in this complex. The results of economic analyses for this complex also are given in Table 3-IV under the column heading "Second Level of Co-siting."

For this second level of co-siting there is a further reduction (7.2 percent) in the total capital investment from 435.2 to 404.1 million dollars. The reasons for this reduction are essentially the same as those for the similar decrease resulting from the first levels of co-siting. Examples of synergistic uses of by-products or co-products here include the usage of by-product carbon monoxide from the calcium carbide plant in the manufacture

TABLE 3-IV

1978 CAPITAL COST COMPARISONS BETWEEN ISOLATED OPERATIONS AND VARIOUS CO-SITING LEVELS

Product	Isolated Operations Capacity (tons/yr)	Isolated Operations Cost* (MM$)	First Level of Co-Siting Cost* (MM$)	Second Level of Co-Siting Cost* (MM$)
Coke	1,000,000	127.2		
Methanol	300,000	69.7	C_3 → 274.3	
Formaldehyde	150,000	99.1		
Calcium carbide	100,000	45.7		C_7 → 404.1
Phosgene	50,000	34.5		
Acetylene	50,000	68.4	C_4 → 160.9	
Isoprene	40,000	53.9		
		498.5	435.2	404.1
(Savings in MM$ over Isolated Operations)		(0)	(63.3)	(94.4)
(Percentage Savings over Isolated Operations)			(12.7)	(18.9)

*Capital cost only. Not included are off-site facilities, land costs, and utilities.

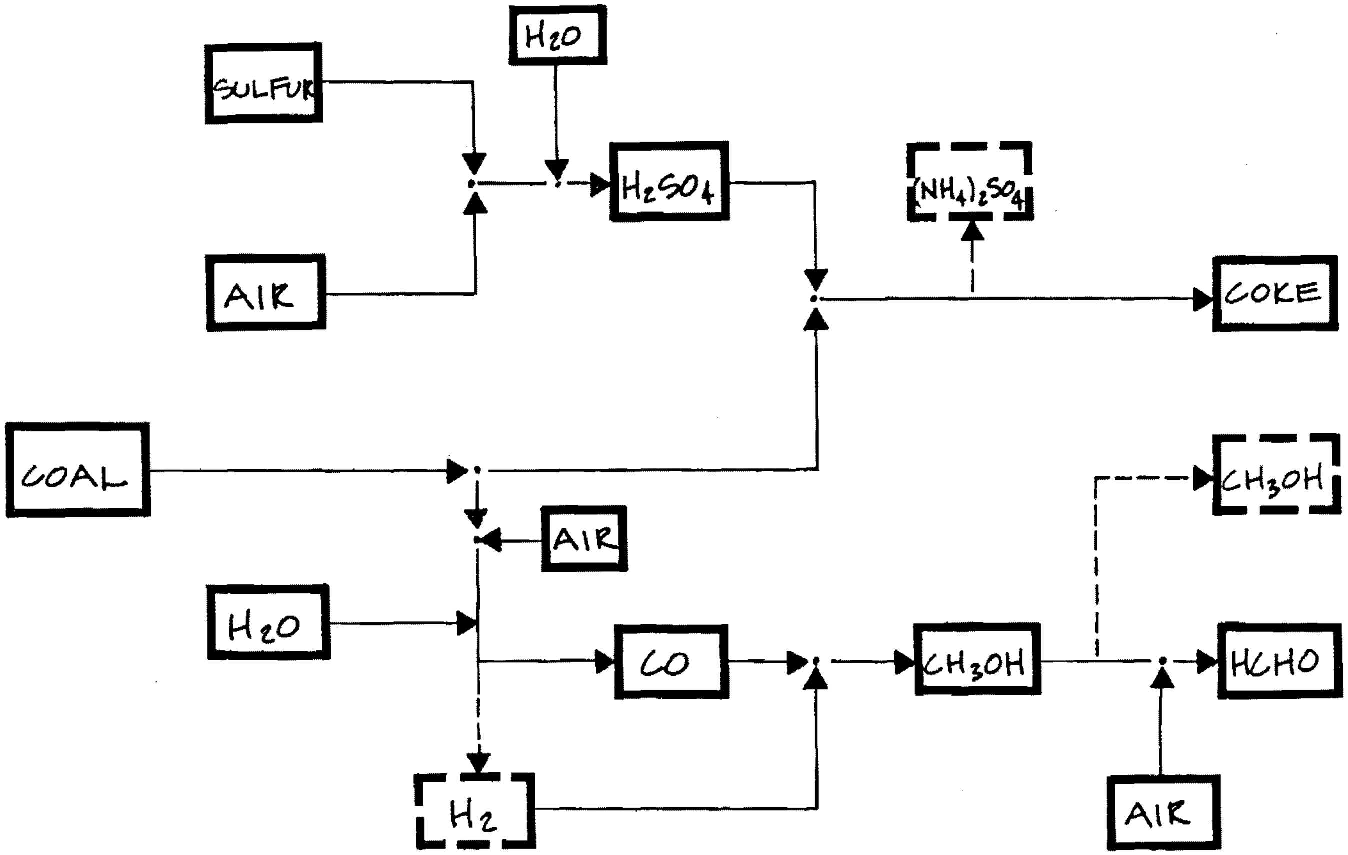

Figure 3-4. First Level of Co-Siting of Plants Producing Three Coal Derivatives, Complex C_3

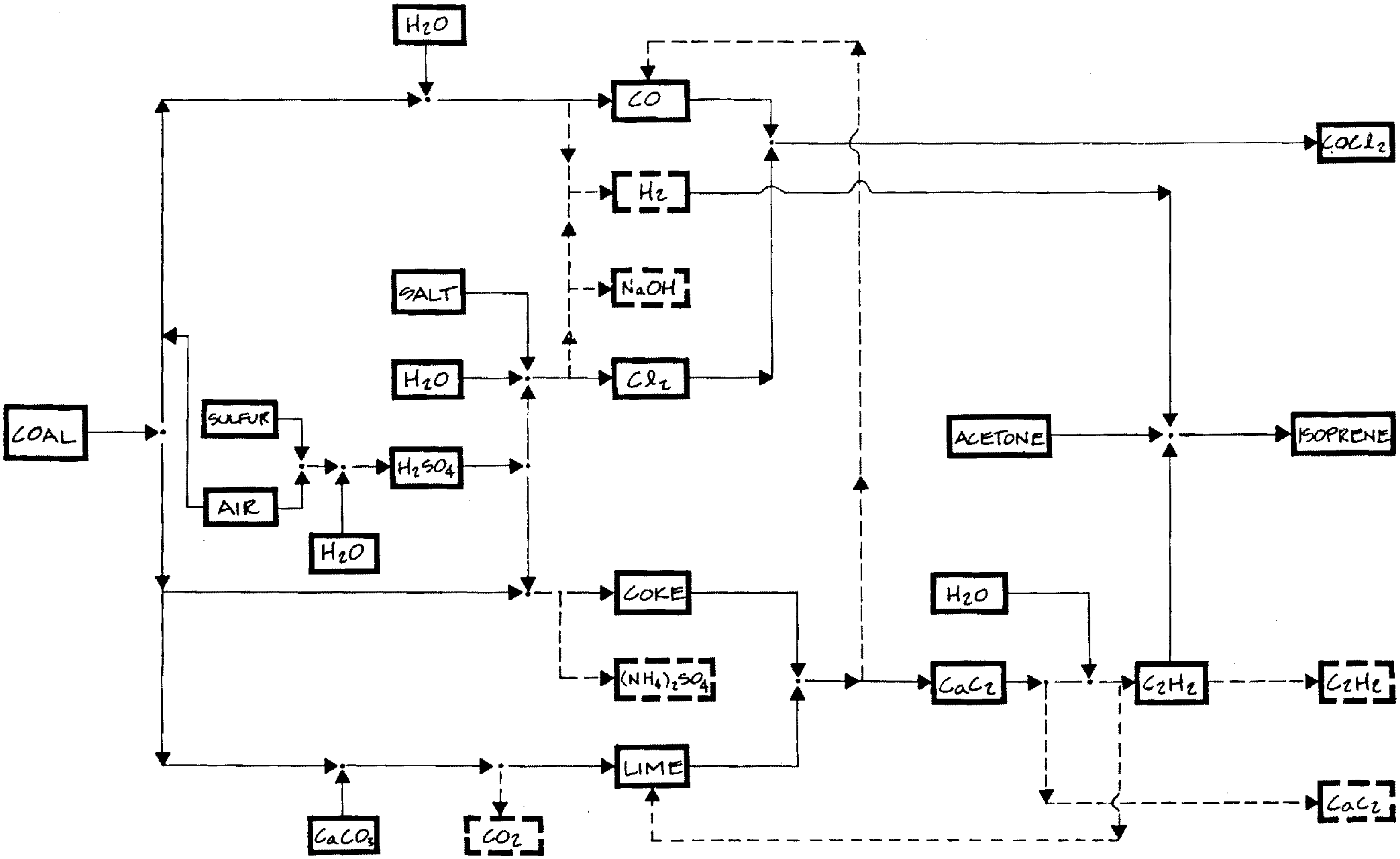

Figure 3-5. First Level of Co-Siting of Plants Producing Four Coal Derivatives, Complex C_4

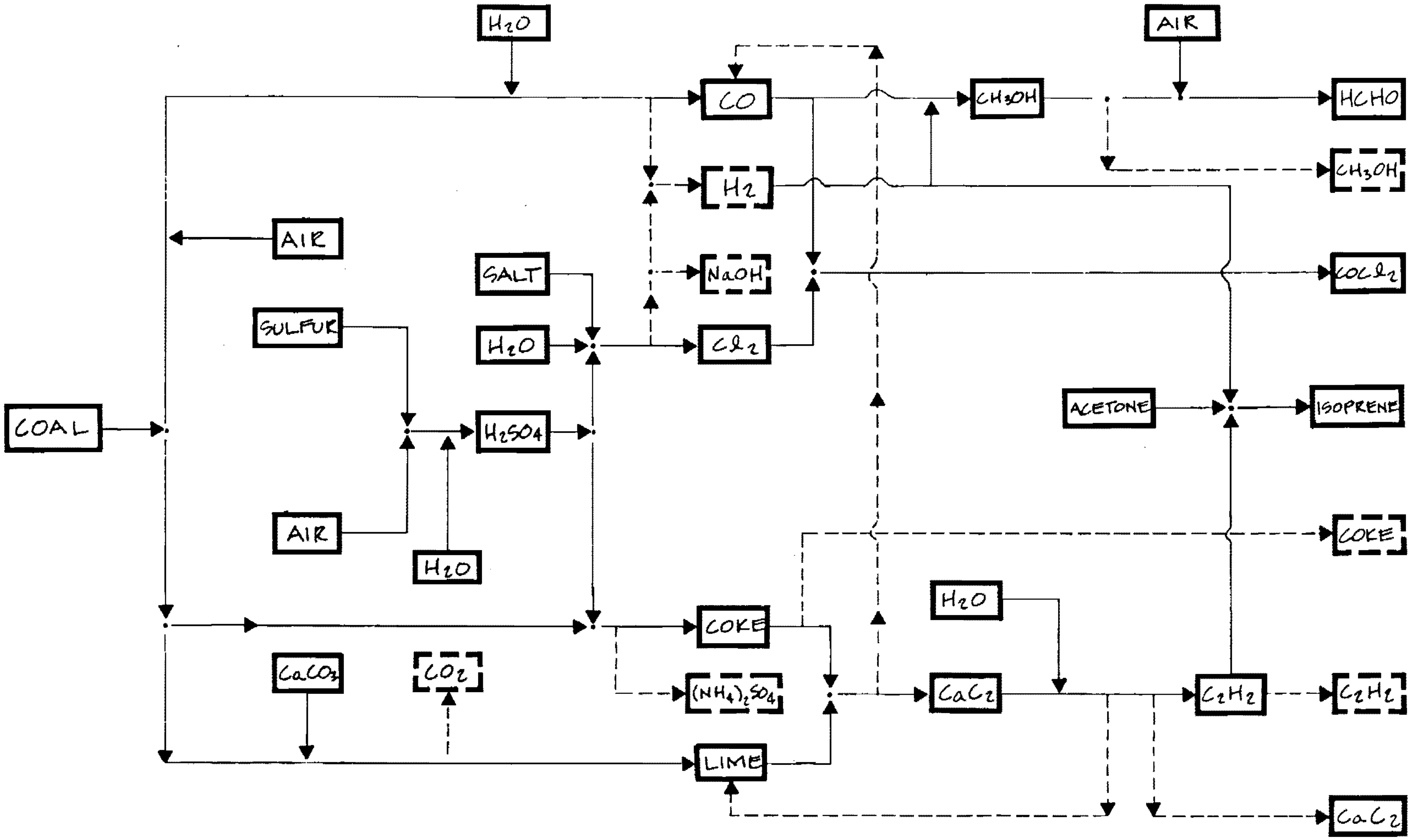

Figure 3-6. Second Level of Co-Siting of Plants Producing Seven Coal Derivatives, Complex C_7

of methanol and the usage of co-product hydrogen from the chlorine plant (required for the production of phosgene) in the manufacture of methanol and isoprene.

The costs of the coke, methanol, formaldehyde, calcium carbide, and carbon monoxide plants account for approximately 85 percent of the total cost of the fully integrated C_7 complex. A sensitivity analysis was thus made to determine the effect of separate variations in the costs of these individual plants on the total costs of the isolated and co-sited operations. The cost of each of these plants was varied by a factor ranging from 0.25 to 2.0.

The results of this analysis are summarized in Table 3-V which shows the savings in total capital costs as well as the savings as a percentage of the total isolated capital costs for the two co-siting levels for the extremes of the individual plant costs considered. The capital-cost savings for coke and formaldehyde are shown as functions of the cost multiplier factor in Figures 3-7 and 3-8, respectively. The figures in parantheses on these plots are the savings as percentages of the total isolated capital costs. Similar linear plots are obtained for the methanol, calcium carbide, and carbon monoxide plants. The slopes of these lines depend on the nature of the role played by the particular plant in the various isolated or co-sited operations. For example, in the isolated operations, a coke plant is not only required for merchant production but also for captive production as required in the calcium carbide, acetylene, and isoprene plants, while in the co-sited operations, only a single but larger coke plant is needed. The slopes of the coke plant lines are relatively steep. On the other hand, only a single

TABLE 3-V

SAVINGS IN TOTAL CAPITAL COSTS (MILLION OF DOLLARS) FOR EXTREMES OF INDIVIDUAL PLANT COSTS

Plant	First Level of Co-Siting Baseline Savings 63.3 MM$		Second Level of Co-Siting Baseline Savings 94.4 MM$	
	Multiplier Factor		Multiplier Factor	
	0.25	2.00	0.25	2.00
Coke	51.8 (14.4)*	78.7 (11.5)	64.7 (17.9)	134.0 (19.6)
Methanol	55.7 (12.2)	73.5 (13.2)	86.8 (19.0)	104.6 (18.8)
Formaldehyde	63.3 (13.7)	63.3 (11.6)	94.4 (20.4)	94.4 (17.2)
Calcium carbide	48.6 (11.0)	82.9 (14.5)	79.7 (18.0)	114.0 (20.0)
Carbon monoxide	52.2 (11.6)	78.1 (13.8)	78.2 (17.4)	116.0 (20.5)

*Numbers in parenthesis represent the savings as a percentage of the total capital cost of the isolated operations.

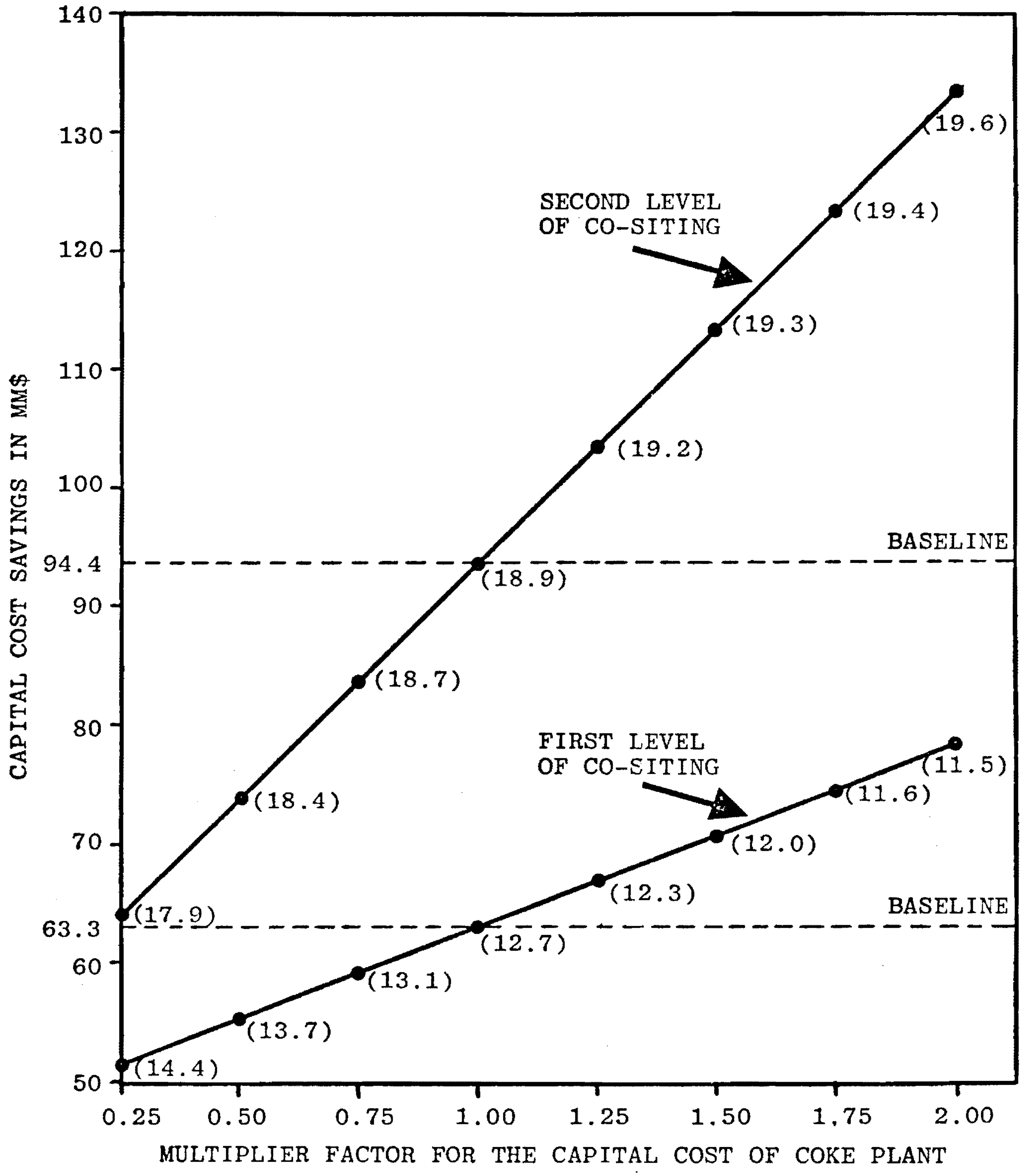

Figure 3.7. Effect of the Capital Cost of Coke Plant on the Savings Due to Co-Siting. (Numbers in parenthesis represent savings expressed as a percentage of the total capital cost of isolated operations.)

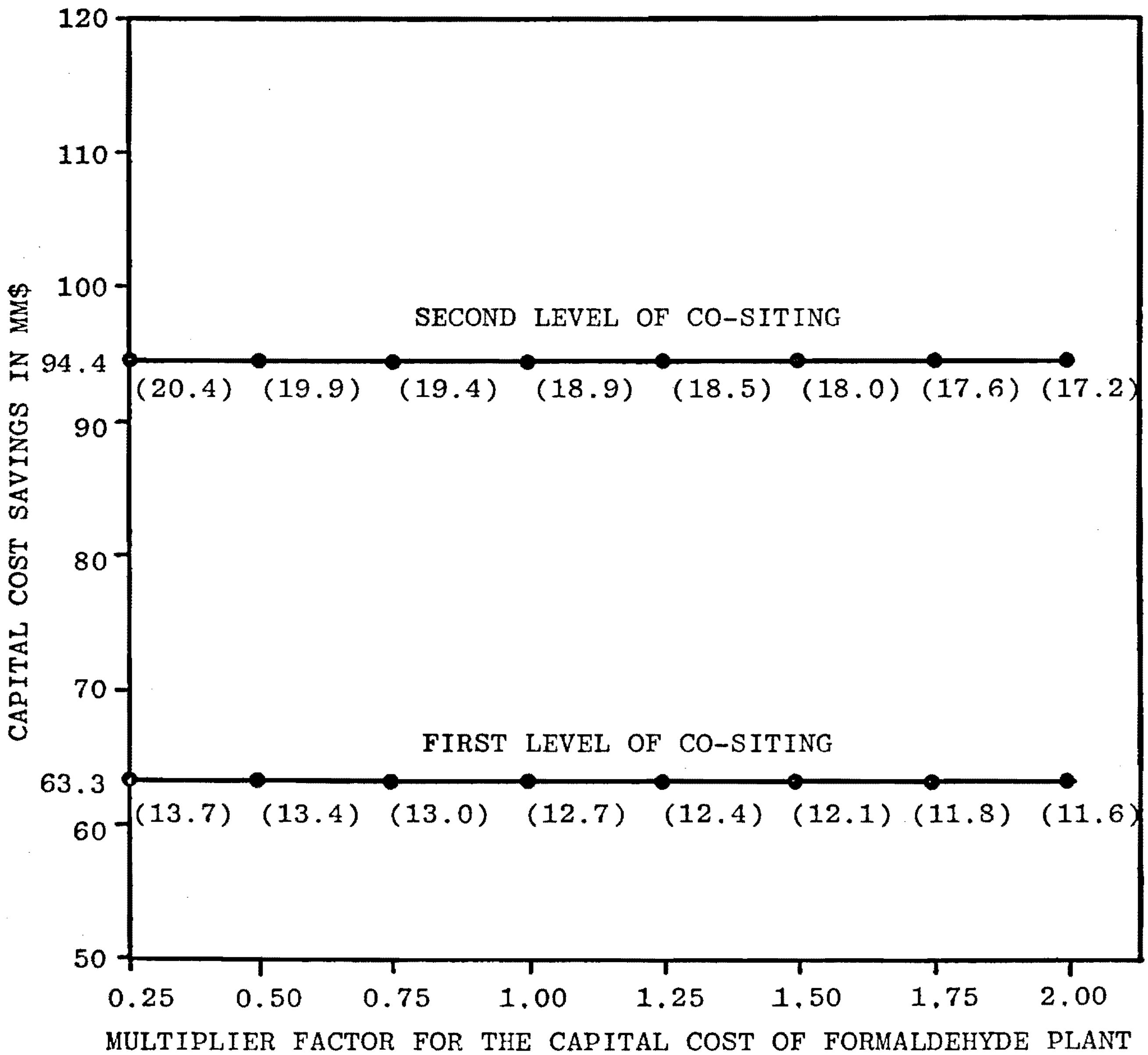

Figure 3.8. Effect of the Capital Cost of Formaldehyde Plant on the Savings Due to Co-Siting. (Numbers in parenthesis represent savings expressed as a percentage of total capital cost of isolated operations.)

formaldehyde plant is needed for merchant and captive production in all levels of operation. Therefore, the slopes of the formaldehyde plant lines are zero.

3.4 - Comparison of Capital Investment Savings Obtained by New and Old Methodologies

The percentage savings in capital investment shown in Table 3-II, obtained using the new methodology developed on this program for the two levels of co-siting, are 20.4 and 35.2 percent, respectively, while the similar quantities shown in Table 3-IV obtained using the old "black-box" methodology are 12.7 and 18.9 percent, respectively. Admittedly, while these complexes are different and are therefore not directly comparable, the large differences in savings obtained by the two methodologies is sufficient to indicate not quantitively but at least qualitively the advantages of the newly developed methodology over our old methodology.

3.5 - Summary

The major objectives of the analyses presented in Sections 3.2 and 3.3 were to demonstrate key aspects of the developed methodology with emphasis on application potential.

The scope of the project budget and schedule did not permit the use of the methodology to characterize an optimized complex for a particular region.

The specific elements of the methodology emphasized in these analyses included:

- Selection of candidate groupings

- Comparison of alternative grouping schemes with respect both to stream interfacing and investment costs.
- Application of systems-integration criteria based on modularization.
- Procedures for effective sensitivity analyses to characterize the effects of data quality (reliability).
- Refinement of previously developed user-interactive computer program for application of methodology.
- Identification of items requiring further refinement and study.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The essential conclusions that were derived from the results of this study can be summarized as follows:

- Synergistic co-siting of industrial activities has excellent potential for achieving both social and economic benefits in the design of industrial complexes.

- Systems-integration criteria and techniques, based on modularization, provided an effective basis for the methodology that was developed in this study, and it is recommended that this methodology be extended through future studies. Our methodology works well in a user-interactive computer mode, as demonstrated in the example analyses that were performed on this study.

- Sensitivity analyses, of the type used in this study, provide a very effective method for characterizing the effects of data quality and specifying data-base requirements.

- The Allen/Page cost estimating technique is a sufficiently detailed and convenient method for realistically estimating costs of modified or unconventional processes for which no literature cost data are available. This method worked well in both the automated and manual modes employed in this study.

- The co-siting methodology developed on this study is particularly attractive for the evaluation of alternative energy sources. For example, where the availability of feedstocks is regionally dependent, the methodology would be useful in identifying and assessing the net benefits that could result from the design of co-sited complexes that can use a variety of feedstocks.

4.2 Recommendations

During the course of this program we have identified advanced design issues requiring in-depth studies and advanced new methodology development that were beyong the available time of our funding resources. These issues are: criteria for optimal sizing and design of co-sited plants; identification of need and criteria for extremely efficient new processes; heuristics for relationships among industry, community planners, and government regulatory agencies; dynamic modelling of co-sited complexes; and co-siting concepts for low-level waste heat utilization. Therefore, it is recommended that the methodology development efforts of the present study be the basis for a new research program having the following specific objectives: (1) to develop, based on advanced concepts for synergistically co-sited industrial activities, a generalized methodology for predictive designs which transcend tradeoff compromises while simultaneously achieving economic benefits (including profitability) and conservation and environmental goals through innovative responses to technical, economic and social forcing functions which, combined, impact on industrial viability; and (2) to demonstrate the methodology through designs and application analyses for carefully selected systems.

APPENDIX A

LIST OF REFERENCES

APPENDIX A

LIST OF REFERENCES

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APPENDIX B

MEMORANDUM OF MINUTES
(INCLUDING ROSTERS, AGENDAS AND WORK PLANS)
OF MEETINGS OF THE PROJECT OVERVIEW COMMITTEE ON 10/28/77 AND 10/27/78

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

November 18, 1977

MEMORANDUM

TO: NSF Synergistic Co-Siting Project Overview Committee

FROM: Jack Spurlock and Henderson Ward

SUBJECT: Minutes of First Overview Committee Meeting on 10/28/77

The first meeting of the Overview Committee for the NSF sponsored grant project "Systems-Integration Requirements for the Synergistic Co-siting of Industrial Activities" (Georgia Tech Project No. B-0488-000) was held on 10/28/77 in Room 303, Baker Building Auditorium, Georgia Tech Engineering Experiment Station. Attendees were:

Mr. Richard L. Cowles
Ms. Anita Fey
Mr. Newt W. Hallman
Mr. Vic Jelen
Mr. R. B. McBride
Mr. John Pratt
Dr. Jude T. Sommerfeld
Dr. Jack M. Spurlock
Mr. Seth Tuttle
Dr. Henderson C. Ward

The meeting followed closely the Agenda and Work Plan which was mailed to committee members prior to the meeting. A copy of this Agenda and Work Plan together with a current roster of Committee members is attached.

At the beginning of the meeting, participants were provided with a notebook containing background information on the project.

A summary of the essential comments, ideas, and suggestions exchanged during the morning session is presented below:

Morning (9-11:45)

Welcome, introductions, major features and potential significance of synergistic co-siting (Spurlock & Ward)

NSF perspective as sponsoring organization (Tuttle)

Project background, objectives, and scope (Ward, Spurlock and Sommerfeld)

Key comments by committee members in response to above presentations:

- A major rationale for co-siting is company survivability (e.g., recent Ethyl Corporation ad to attract co-siting partners).
- Considering the costs of detailed economic estimates for industrial ventures, the most realistic approach on this project is to use approximate techniques and attempt to establish maximum and minimum probable costs.
- Advisable to seek return on investment (ROI) criteria from user industry.
- Co-siting methodology based only on chemical plants of little interest or value to large chemical companies but could be of considerable value to the smaller chemical companies producing a limited number of products.
- Co-siting methodology based on mix of chemical and non-chemical activities (such as agricultural, food, forestry) could be of value to the large chemical companies.
- Great need exists for development of schemes to utilize low temperature energy (less than 250^{o}F) presently abundantly available.
- Incentives needed to promote industry acceptance of co-siting.
- Refineries are continually updating both processes and equipment to meet competitive pressures.

Noon (11:45-1:30)

The Committee had lunch together in the Georgia Tech Student Union and afterwards toured some of the current Georgia Tech Energy and Environmental Research Activities. These included the newly completed 400 kw (thermal) solar power-generation research facility and the pilot plant for the pyrolytic conversion of agricultural wastes into industrial fuels.

Afternoon (1:30-4:15)

During the afternoon Workshop Session, attention was focused on three categories. The essential comments, ideas, and suggestions exchanged during this session are summarized below by categories.

Category I -- Feedstocks and Fuel Alternatives; Energy Consumption and Conservation

- Tar sands a possible feedstock source. Less potential trouble than shale oil. Large sources available in South America and Canada. Great Canadian Oil Sands (GCOS) in operation. Now competitive, but only because it was built with 1960's money at about $350 million.
- Shale-oil technology essentially available; awaiting economics.
- Coal probably least attractive feedstock alternative for the near future.
- Coal will be used principally as boiler fuel. Stationary use; not attractive for transport.
- Limited interest in hydrogen use. Viewed as just a reactive chemical.

Category II -- Land Use, Site Selection and Environmental Constraints

- Environmental constraints vary from state to state and from region to region.
- A key site-selection factor is to provide most economic route from raw material source to market.
- Many companies have had bitter experiences in site selection and purchase-Shell in Delaware, Dow in California, etc.

- Low temperature applications abound. Need key matching criteria development.

- Industry usually buys land in sections (1 section = 1 square mile = 640 acres). Typical minimum is 1 section.

- Industry usually purchases about 2 to 3 times minimum land required.

- Industry "rules of thumb" --

  on-site: $20 million of equipment/acre
  off-site: $ 1 million of facilities/acre.

- Maximum realistic construction labor force is approximately 2,000 at any time.

- About all that can be built at one site at one time, based on labor force saturation of the site, is equivalent to one world-scale ethylene plant; other associated units would have to await completion of this major unit.

- Houston is considered to have the best labor pool of skilled refinery construction workers.

- East coast sites are desirable but are practically unavailable due to various restrictions. Therefore, tradeoffs favor southern and southwestern sites.

- Typical distribution of investment in increased refinery capability is 85% add-on to existing facilities and 15% for new ("green fields") construction.

- Site selection should avoid scenic rivers and parks (existing and planned).

<u>Category III</u> -- <u>Project Methodology</u>

- Better source of current plant and equipment costs is construction firms and vendors rather than detailed flow sheet analysis.

- In considering regional impacts, it is best to favor sites where the industry is needed and wanted and adequate construction labor is available. For example, Houston and Corpus Christi are good; Wood River,(Illinois),New Jersey, New York and St. Louis are bad.

- <u>Chemical Week</u> publishes an annual rating of industrial sites.

- Site-selection analysis should seek to minimize overall transportation costs (e.g., avoid backtracking).

- State and local taxes are not major considerations in site selection but can be a "tie breaker,"
- Water availability and amount is a most important consideration if heat rejection requirements are large. For example, shortages of water where oil shale is abundant pose a major problem.
- Stable political environments are important regional considerations to avoid unfavorable changes in terms and conditions of plant sitings.
- Avoid unethical dealings in site acquisition.
- It is possible to completely enclose ("can") a plant environmentally for a price. Examples are refineries in Los Angeles basin and Scandinavian countries.

The meeting was adjourned at 4:15 PM, slightly ahead of schedule, to allow a number of the Committee members to meet plane schedules. It was announced that the next meeting of this Committee is tentatively scheduled for late spring or early summer of 1978.

FOOTNOTES:

A. Materials received from Committee members during meeting

(Cowles) 1. Copy of draft final report on cogeneration study by Research Planning Associates, Inc. (sponsored by Federal Energy Administration).

(Hallman) 1. James, R.B., Fickel, R.G., and Sepiol, S.J., "A Realistic Approach to Energy Conservation," Paper presented at the UOP Technology Conference, October, 1977.

2. Collection of news clippings on industrial energy conservation initiatives (principally cogeneration).

B. Material to be forwarded by Committee members

(Cowles) * 1. Copy of report: Barnes, R.W., "The Potential Industrial Market for Process Heat from Nuclear Reactors," Dow Chemical Company (sponsored by ERDA-Oak Ridge), January 1976.

* 2. MIUS Bibliography, NBS Special Publication 489, (U.S. Dept. of Commerce & HUD).

* 3. "Energy Conservaton and Environment Publications," Federal Energy Admin. conservation publications bibiliography, July 1977.

* 4. Copy of report: Gyftopoulos, E.P., et al, "Potential for Effective Use of Fuel in Industry," Thermo Electron Corp., for the Ford Foundation, April 1974.

(McBride) * 1. Shiroka, K. and Umeda, T.,"Energy Conservation in Petroleum Refineries - Current Status and Future Trends," Chemical Economy and Engineering Review, 18-25, November 1976.

* 2. Union Carbide videotape, "Cajun Country".

(Jelen) 1. Kanawha Valley Study, Corps of Engineers -- Ohio River Division, Cincinnati, Ohio. Study deals with land use and groupings.

* -Received by date of preparation of these minutes.

AGENDA AND WORK PLAN FOR

FIRST MEETING OF OVERVIEW COMMITTEE

NSF SYNERGISTIC CO-SITING PROJECT

303 Baker Building (Auditorium)
Georgia Tech Engineering Experiment Station

October 28, 1977

9:00 - 9:15	Welcome and Introductions
9:15 - 9:45	Major Features and Potential Significance of Synergistic Co-Siting
9:45 - 10:00	NSF Perspective as the Sponsoring Organization (Mr. Seth Tuttle)
10:00 - 10:45	Project Background, Objectives, and Scope
10:45 - 11:45	General Discussions of Trade-off Factors such as:

- Ownership (Management Structures for Co-siting Ventures)
- Operational Reliability Interdependency among Coupled Units
- Effect on Protection of Proprietary Processes
- Requirements for and Availability of Adequate Land for All Units
- Proximity to Markets, Raw Material and Other Resources for All Units
- Regional and Community Impact (On and by the Co-sited Complex)

11:45 - 12:45	Lunch
12:45 - 1:30	Tour of Georgia Tech Energy and Environmental Research Activities
1:30 - 4:45	Workshop Session -- This will consist of an informal exchange of ideas, information and intuitions on several topics of importance to the project. Solutions, or approaches to solutions, to the problems listed on the attached sheet will be discussed.
4:45 - 5:00	Summary and Assessment of Workshop Results
5:00	Adjournment

GT EES

Key Problem Areas as Topics for Workshop Session

Category I -- Feedstock and Fuel Alternatives; Energy Consumption and Conservation:

- What are the current and future problems and options?
- What are the appropriate roles for various synergistic co-siting modes in contributing solutions and improving economic attractiveness of options?

Category II-- Land Use, Site Selection and Environmental Constraints:

- What data are available on land requirements for various chemical processes?
- What data are available on emission and effluent control requirements for various chemical processes?
- In its current and future site planning, how is industry responding to environmental control pressures (in the U.S. and abroad)?
- How can co-siting applications improve site selection, planning and approval processes for industry and regional planners?
- What are the key factors that must be considered in applying co-siting concepts to land-use planning?

Category III- General Discussion on Project Methodology, Including:

- Cost estimating techniques
- Flowsheet availability
- Process matching criteria
- Process coupling interfaces
- Graphical-design computer techniques
- Data-base requirements

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GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

November 17, 1978

MEMORANDUM

TO: NSF Synergistic Co-Siting Project Overview Committee

FROM: Jack Spurlock and Henderson Ward

SUBJECT: *MINUTES OF SECOND OVERVIEW COMMITTEE MEETING ON 10/27/78*

The second meeting of the Overview Committee for the NSF sponsored grant project "Systems-Integration Requirements for the Synergistic Co-Siting of Industrial Activities" (Georgia Tech Project No. B-0488-000) was held on October 27, 1978 in Room 102, Baker Building, Georgia Tech Engineering Experiment Station. Attendees were:

Mr. Richard L. Cowles
Mr. Newt W. Hallman
Mr. Vic Jelen
Mr. R.B. McBride
Mr. John Pratt
Dr. Jude T. Sommerfeld
Mr. Dalip K. Sondhi
Dr. Harold Spuhler
Dr. Jack M. Spurlock
Dr. Henderson C. Ward

The meeting followed generally the Agenda and Work Plan, a copy of which is attached together with an updated roster of committee members. Unfortunately, mailed copies of the Agenda and Work Plan failed to reach most of the committee members prior to the meeting, so additional copies were made available at the beginning of the meeting; at that time each participant was also provided with a folder containing information pertinent to the items to be discussed.

A summary of the essential comments, ideas, and suggestions exchanged during the morning session is presented below:

MORNING (9:00 - 11:45)

1. Welcome, introductions, brief discussion of Agenda and folder items, and overall view of past project year (Spurlock and Ward).

2. Past project year in review and next six months (Sommerfeld, Sondhi, Spurlock and Ward).

3. Key comments by committee members in response to above presentations:
   - Relatively few chemicals have large energy impact; 6 chemicals account for approximately 85% of energy used, 20 for 90%, and 100 for about all.
   - Dollars must be optimized for private users to accept co-siting.
   - Not only energy used but energy levels must be considered.
   - Chemical storage of solar energy was cited as an important research area, with particular reference to batteries.
   - Data source should not be limited to southeastern U.S.
   - American public has an emotional and subjective block against industrial plants, particularly blocking refinery construction on the East coast.
   - Rational decision-making must be an inherent goal of project.
   - Government regulations are confusing, but when industry knows and understands these regulations, it is willing to follow them.
   - Need for more example cases was stressed, and Appalachian Region was suggested as a topnotch possibility.
   - Industries which license processes were suggested as a major source of data (on non-proprietary processes). The following companies were offered as examples: UOP, Shell Development, Texaco Development, Scientific Design, Chevron Research, Dow, Monsanto, DuPont, Union Carbide, BSF, Phillips, Kellogg, and Foster-Wheeler. Requests should be addressed to licensing departments.

NOON (11:45 - 1:00)

The committee had lunch together in the Georgia Tech Student Union and afterwards toured the Georgia Tech Solar Advanced Components Test Facility located on the Tech campus.

AFTERNOON (1:00 - 3:40)

During the afternoon session, attention was focused mainly on two broad categories. The essential comments, ideas, and suggestions exchanged during this session are summarized below by categories:

A. Category I — Land Use:
   - Land purchased by industrial companies is based on their viewpoint of the future, their financial position, availability of land, land prices, neighborhood, etc.
   - 400-1000 acres estimated as requirement for co-sited complex.
   - Companies inclined to purchase as much land as is available if price is reasonable.
   - Estimated correlation between land and money spent on chemical facilities is about $1 billion/1000 acres; as an example, a plant recently built in Saudi Arabia was cited at $1.5 billion/1500 acres.
   - Europe in general, Holland in particular, are excellent examples of optimum land use for industrial purposes; highly limited land there requires careful planning and far-sightedness; national interest requirements placed above private interests.

- It would be difficult to put together a complex as a complete package since investor's money would be tied up too long; best idea would appear to be that of building up complex gradually.
- Underdeveloped countries provide a possible fertile ground for co-sited complexes.
- In connection with the $1 billion/1000 acre rule of thumb, it was suggested that it would be interesting to correlate diverse information such as the amount of steel used in a chemical facility per pound of product.

B. Category II — Project Extension

1. How big is big enough?

- Financing of chemical industries is very important and very complicated. The competition is high. This is often the dominant factor in determining size.
- Energy inflation a key factor.
- Political ramifications need to be considered.
- To achieve a balance between viable economy and risk-taking, there is a need for a better technical decision-making base.
- Need to increase shared risk-taking among industry.
- Need to consider equipment size – shop fabrication or field fabrication options.
- Limiting factor on size could be financing the current growth rate of chemicals (4-5%).

2. Cosmetic Design

- Odors and dusts are the most offensive elements of a chemical plant – much more so than visual effects.
- Pendulum of public opinion against building of chemical plants has begun to shift toward a more positive attitude.
- National disgrace to chemical industry is tank cars going off the rails and highways being torn up by heavy chemical-conveying trucks.

3. Dynamic Modelling

- Could possibly be very valuable to government agencies but of limited interest to industry which basically makes its own predictions.
- Difficulties in amassing data base and determining variable interrelations stressed.

4. Multiple-Use Plants

- Viewed as extremely expensive option due to cleanup and contamination problems.
- Presently used for producing commodity chemicals such as pesticides.

5. Heuristics

- Need exists to develop methodology to treat states of transition, mixing non-quantifiable (probabilistic) variables with quantifiable (physical, technical) variables to seek impact assessments, option analysis, etc. for policy formulation; i.e., a type of "what-if" analysis to determine options and their consequences.
- Wharton School is doing an NSF study in this general area.

6. Low-Level Waste Heat Recovery

- Low-level heat-driven refrigeration systems were discussed.
- It was suggested that perhaps low-level heat could be utilized as energy for biological processes (i.e., greenhouses, etc.) and that perhaps the general area of biological processes should be explored. Beer, pharmaceuticals, and sewage and waste treatment plants might be possible users of low-level heat.
- Agricultural uses such as fish farms and heating the soil (to extend growing season) might be explored.

At the end of the meeting, several project papers were made available to the participants and a copy of a paper on a low-level heat-driven refrigeration system was promised to be sent to the committee members. A copy of this paper is enclosed.

The meeting was adjorned at 3:40 PM to allow a number of committee members to meet plane schedules. No date was set for the next committee meeting.

JMS:HCW/cy

Enclosures

AGENDA AND WORK PLAN FOR

SECOND MEETING OF OVERVIEW COMMITTEE

NSF SYNERGISTIC CO-SITING PROJECT

303 Baker Building (Auditorium)
Georgia Tech Engineering Experiment Station

October 27, 1978

9:00 - 9:15	Welcome and Coffee
9:15 - 10:15	The Past Project Year in Review
10:15 - 10:30	The Next Six Months
10:30 - 11:00	New Areas Identified for Study in Extension of Present Project
11:00 - 11:45	General Discussion of Project Extension
11:45 - 1:00	Lunch
1:00 - 3:45	Workshop Session--This will consist of an informal exchange of ideas, information and intuitions on several topics of importance to the project. Solutions, or approaches to solutions, to the problems listed on the attached sheet will be discussed
3:45 - 4:00	Summary and Assessment of Workshop Results
4:00	Adjournment

Key Problem Areas as Topics for Workshop Session

Category I -- Update and/or New Developments in Categories Discussed at First Meeting on 10/28/77

- Feedstocks and Fuel Alternatives, Energy Consumption and Conservation
- Land Use, Site Selection; and Environmental Constraints
- Project Methodology

Category II -- Process Analysis, Safety, Reliability, and Control

- What data are available on number of major processing units in chemical processes?
- Effect of co-siting applications on process safety requirements
- Effect of co-siting applications on process reliability
- Effect of co-siting applications on process control
- Computer-graphic techniques

Category III -- Co-Siting of Chemical and/or Non-Chemical Activities

- Basis for co-siting
- Availability of data on non-chemical activities
- Incentives for co-siting
- Possible co-siting candidates

CO-SITING OVERVIEW COMMITTEE ROSTER: 10/11/78

1. Mr. Richard L. Cowles (202)566-4661
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2. Mr. Newt W. Hallman (312)391-2511
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APPENDIX C

USER-INTERACTIVE COMPUTER PROGRAM

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USER-INTERACTIVE COMPUTER PROGRAM

C.1 General Description

This Appendix describes the application of a user-interactive computer program that was developed to facilitate and encourage the use of synergistic co-siting methodology. It provides for the screening, selection, and economic comparison of co-sited industrial groupings. The program involves an interrogative-conversational format and consists of the following list of questions and guideline statements:

1. HAVE YOU USED THIS PROGRAM BEFORE?
2. DO YOU WANT A DESCRIPTION OF THIS PROGRAM?
3. DO YOU WANT A LIST OF THE 19 INDUSTRIES INCLUDED IN THE DATA BASE OF THIS PROGRAM?
4. DO YOU WANT A LIST OF SOURCES OF DESCRIPTIVE INFORMATION FOR INDUSTRIES IN THE DATA BASE?
5. WOULD YOU LIKE TO PERFORM A SEARCH FOR CO-SITING CANDIDATES FOR A SPECIFIC CORE OF INDUSTRIES?
6. HOW MANY INDUSTRIES CONSTITUTE THE CORE OF THE COMPLEX YOU ARE CONSIDERING? (THE CORE MAY CONSIST OF NEW INDUSTRIES ONLY, EXISTING INDUSTRIES ONLY, OR BOTH NEW AND EXISTING INDUSTRIES.)
7. LIST THE CODES OF THE INDUSTRIES IN THE CORE.
8. AT THIS POINT WOULD YOU LIKE TO SPECIFY ANOTHER CORE OF INDUSTRIES AND BEGIN ANOTHER SEARCH FOR CO-SITING CANDIDATES FOR THIS CORE?
9. WOULD YOU LIKE TO PERFORM AN ECONOMIC ANALYSIS FOR A SPECIFIC COMPLEX?
10. FOR HOW MANY INDUSTRIES IN THE COMPLEX WILL YOU SPECIFY MERCHANT CAPABILITIES?
11. LIST THE CODE NUMBERS OF THE INDUSTRIES IN THE COMPLEX AND THEIR MERCHANT CAPACITIES, I.E., INDUSTRY NUMBER, CAPACITY (TONS/YEAR).

12. SEVERAL OPTIONS ARE AVAILABLE FOR THE ANNUAL INCREASE IN THE COST OF CHEMICAL PLANTS. INCORPORATED IN THIS COMPUTER PROGRAM, AS OPTION (1), FOR THIS RATE OF INCREASE IS THE AVERAGE MARSHALL-SWIFT INDEX FOR THE YEAR 1975, WITH AN ALLOWANCE FOR AN ANNUAL AVERAGE INCREASE OF 4.5 PERCENT FOR YEARS BEYOND 1975 IN WHICH A PLANT MIGHT BE CONSTRUCTED. OPTION (2) PROVIDES FOR THE SPECIFICATION OF ANY MARSHALL-SWIFT INDEX OF INTEREST. OPTION (3) IS A MODIFICATION OF OPTION (1) WHICH USES THE MARSHALL- SWIFT INDEX INCORPORATED IN THE PROGRAM FOR THE YEAR 1975, BUT PERMITS THE USER TO SPECIFY AN ANNUAL INCREASE OTHER THAN 4.5 PERCENT BEYOND THE 1975 INDEX VALUE.

    TYPE IN THE OPTION YOU PREFER.

13A. TYPE IN THE YEAR OF INTEREST (OPTION 1 ONLY).

13B. TYPE IN THE MARSHALL-SWIFT INDEX OF INTEREST (OPTION 2 ONLY).

13C. TYPE IN THE YEAR OF INTEREST (1975 OR LATER) AND THE ANNUAL PERCENT OF INCREASE (OPTION 3 ONLY), I.E., YEAR, ANNUAL PERCENT.

14. DO YOU WISH TO ANALYZE THE SAME COMPLEX BUT WITH A DIFFERENT ANNUAL INCREASE IN PLANT COSTS?

15A. DO YOU WANT TO PERFORM AN ECONOMIC ANALYSIS FOR ANOTHER COMPLEX?

15B. DO YOU WANT TO USE THE SAME PLANT-COST BASIS IN THIS ANALYSIS YOU CHOSE IN RESPONSE TO STATEMENTS 12 AND 13 IN THE PREVIOUS ANALYSIS?

16. WOULD YOU LIKE TO SPECIFY ANOTHER CORE OF INDUSTRIES AND BEGIN ANOTHER SEARCH FOR CO-SITING CANDIDATES FOR THIS CORE?

As can be seen from the above list, the format utilizes procedural and explanatory steps that are tailored for the experience level of the individual user. Responses selected by the user for each of the questions or guideline statements determine the sequence of further steps in the procedural format. This is demonstrated in the logic diagram for the overall program shown in Figure C-1.

The overall functions performed for the user by the computer program are accomplished in three major groupings of the 16 statements. These groupings are explained below.

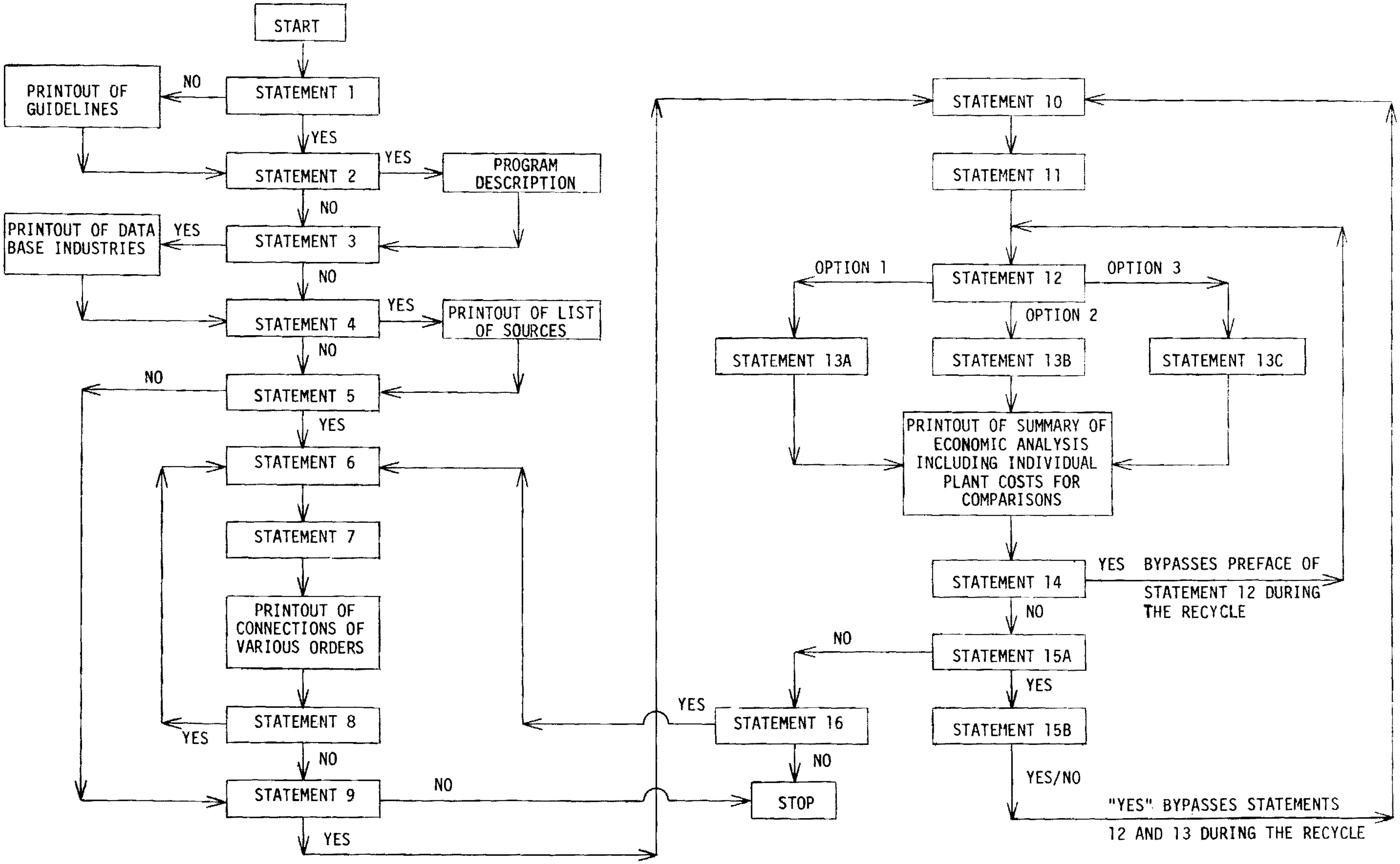

Figure C-1. Logic Diagram of the User-Interactive Computer Program

GROUP 1 (Statements 1-4): This segment of the program provides the user with background information relating to steps in the program and items in the data base. It is necessary that a new user (i.e., unskilled in the use of the program) request the list of chemicals which are included in the data base of the program in order to obtain the code numbers of chemicals or industries which will be required as input information in response to later statements.

An option is also available for the user to request a list of references which may be consulted for general information on chemical processes.

GROUP 2 (Statements 5-8): This segment of the program searches for co-siting candidates and prints connections of various orders. The user is required to provide a "core" which may consist of one or more than one chemical commodity. For example, a local abundance of coal might suggest a coal-based complex and in this case coal alone would constitute the "core." In general, as far as the user is concerned, there are no restrictions regarding chemicals or their number that may comprise the "core," as long as they are listed in the data base.

The printout consists of items listed under the titles "COMPONENT 1" and "COMPONENT 2." The item(s) listed under "COMPONENT 1" are the chemicals which the user provides as the "core." The chemicals under "COMPONENT 2" are the appropriate potential co-siting candidates.

The term "order of connection" indicates how the various commodities are connected. If the commodities are directly coupled, then the connection order is one. If the coupling is through one intermediate component, the order is two. If the coupling is through two intermediate components, the order is three, etc.

The computer program permits only one first-order connection between a product and each of the input materials for a given process. Therefore, the choice for this connection must be the one relating to the principal product and the by-product or by-products are then considered to be second-order connections with the materials that are inputs to the process. In turn, the principal product and the by-product(s) of a process are considered to be related by a first-order connection (i.e., the principal product causes the other(s) to be produced without any further chemical reaction steps). Also, only the lowest connection order for two materials will be shown in the computer printout.

GROUP III (Statements 9-16): This segment deals with the economic analysis for a chosen complex. Following is an explanation of the terms and abbreviations which appear in the printout of the economic analysis:

CAPTIVE PRODUCTION - Production of a chemical which is consumed within the complex itself. A negative value indicates generation of a by-product.

MERCHANT PRODUCTION- Production which will be shipped to markets outside the complex (i.e., external).

TOTAL PRODUCTION - Sum of captive and merchant productions.

REMARKS - Displays the role of certain chemicals either as by-products or as raw materials for the convenience of the user.

PLANT COST - Costs shown are capital costs only. Not included are off-site facilities, land costs, and utilities.

PRODUCT VALUE - Product market values are computed and displayed for items which have a non-zero merchant production.

RAW MATERIAL COST - Market value of raw materials consumed in the complex.

BY-PRODUCT CREDIT - Credit value associated with the generation of by-products which are shipped outside the complex.

POWER - Power consumed for the total production of a chemical. Shown for only those items with which a plant cost is associated.

TPY - Tons/year.

MM$ - Millions of dollars

MM$PY - Millions of dollars per year.

MW - Megawatts

The list of 19 "industries" in the data base, which the computer program will provide if so instructed in Statement 3, includes three basic raw materials identified by ** and three by-product materials identified by * (a printout of these "industries" is shown in Section C.2.2). Due to the roles of these materials in the various processing schemes considered in the methodology, merchant capacities should not be specified for any of these materials in response to Statement 11. However, any of these materials may be considered as core industries in response to Statement 7.

C.2 Illustrative Example

C.2.1 Description and Discussion

The essential features and applicational significance of this user-interactive program can be characterized by application to the example case discussed in Section 3.2 involving the identification and economic comparison, for the year 1979 based on the Marshall-Swift Index, of feasible co-siting groupings in a coal-based syngas complex. This will demonstrate the use of the interactive computer procedure as well as demonstrate manual selection procedures in determining feasible groupings.

The computer printout for this illustrative example is provided in Section C.2.2 and has the statement format described earlier in Section C.1. Guidelines for and responses to the various computer statements are as follows:

- Statements 1-4. The first 4 statements of the format are straightforward and prepare the user, based on his background, for the computer procedure. For illustrative purposes, the responses were: -- "yes", "no", "yes", "no", respectively.

- Statement 5. Since in this example, the co-siting candidates were selected manually and only one industry (coal) constituted the core, the response was "no" and the program went directly to Statement 9.*

*The automated search routine, performed by way of Statements 6 through 8, could have been used to determine connections. However, because of the small size of the data base that incorporates the Allen/Page cost-estimation method, the automated routine is not particularly useful here. The search methodology has been retained in the program, since the data base can be expanded to include up to 500 commodities.

- Statement 9. - The response was "yes," and Complex C_1 was the basis for the first economic analysis which begins with the response to Statement 10.

- Statement 10. - Since there are three industries (ammonia, formaldehyde and methanol) having merchant capacities in Complex C_1, the response was "3."

- Statement 11. - The response was "1", 100000"; "6", "20000"; "7", "100000." The respective code numbers were obtained from the data-base printout of Statement 3, and the merchant capacities are those selected to be relevant for these products.

- Statement 12. - Since this illustrative example specified economic comparisons for the year 1979, the response was "2." Note that as pointed out in the computer printout for Statement 12, the user has two other options available to him.

- Statement 13B. - Since the year specified in this illustrative example was 1979, the response was "600", the Marshall-Swift index for 1979. At this point, economic analyses were printed by the computer for the isolated operations (when not co-sited) for comparison purposes and for the co-sited operations (Complex C_1). It should be noted that the capital costs, power requirements, etc., associated with each of the isolated operations shown in the economic analyses include all of the supporting plants needed.

- Statement 14. - Not desiring at this point to use any other basis for estimating plant costs, the response was "no."

- Statement 15A. - Desiring now to analyze Complex C_2, the response was "yes."

- Statement 15B. Desiring to use the same plant-cost basis previously used, the response was "yes." This response recycled the procedure back to Statement 10 and appropriate information was then provided to the computer by the user for Complex C_2 in response to Statements 10, 11 and 14. Complex C_{12} was then analyzed by a repeat of this procedure.

- Statement 16. - Having completed the desired analyses, the response was "no." This response automatically terminates the computer procedure.

The results of this entire example procedure permit the user to compare the relative cost benefits associated with the various levels of co-siting. Capital costs comparisons are summarized in Table 3-II.

C.2.2. Computer Printout for Illustrative Example

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THIS PROGRAM WAS DESIGNED AND COMPUTERIZED DURING
1980 AS PART OF A STUDY INVESTIGATING SYNERGISTIC
CO-SITING CONDUCTED BY THE ENGINEERING EXPERIMENT
STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY UNDER
CONTRACT TO THE NSF, WASHINGTON, D.C.

1.  HAVE YOU USED THIS PROGRAM BEFORE ?
? YES

2.  DO YOU WANT A DESCRIPTION OF THIS PROGRAM ?
? NO

3.  DO YOU WANT A LIST OF THE 19 INDUSTRIES
    INCLUDED IN THE DATA BASE OF THIS PROGRAM ?
? YES

           NO.  INDUSTRY NAME         NO.  INDUSTRY NAME
           ---  -------------         ---  -------------

           **8  AIR                     7  METHANOL
             1  AMMONIA                *2  NITROGEN
           *19  CARBON DIOXIDE         11  OXYGEN
            13  CLAUS OFF-GAS           5  RAW SYNGAS
          **12  COAL                   14  SNG
             4  DD SYNGAS              15  SULFUR
             6  FORMALDEHYDE           17  SULFURIC ACID
             9  GASOLINE               18  UREA
             3  HYDROGEN             **10  WATER
           *16  HYDROGEN SULFIDE

           *  BY-PRODUCTS ONLY
           ** RAW MATERIALS ONLY

4.  DO YOU WANT A LIST OF SOURCES OF DESCRIPTIVE
    INFORMATION FOR INDUSTRIES IN THE DATA BASE ?
? NO
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5.  WOULD YOU LIKE TO PERFORM A SEARCH FOR COSITING
    CANDIDATES FOR A SPECIFIC CORE OF INDUSTRIES ?
? NO

9.  WOULD YOU LIKE TO PERFORM AN ECONOMIC ANALYSIS
    FOR A SPECIFIC COMPLEX ?
? YES

10.  FOR HOW MANY INDUSTRIES IN THE COMPLEX WILL YOU
     SPECIFY MERCHANT CAPACITIES ?
? 3

11.  LIST THE CODE NUMBERS OF THE INDUSTRIES IN THE
     COMPLEX AND THEIR MERCHANT CAPACITIES, I.E.,
     INDUSTRY NUMBER, CAPACITY (TONS/YEAR)
?    1, 100000
?    6,  20000
?    7, 100000

12.  TYPE IN THE OPTION YOU PREFER
? 2

13B.  TYPE IN THE MARSHALL-SWIFT INDEX OF INTEREST
      (OPTION 2 ONLY)
? 600.0
```

ISOLATED OPERATIONS PRODUCING AMMONIA

ID	PLANT/MATERIAL	CAPTIVE PRODN. TPY	MERCHANT PRODN. TPY	TOTAL PRODN. TPY	PLANT * COST MM$	PRODUCT VALUE MM$PY	RAW MATL. COST MM$PY	BY-PRODUCT CREDIT MM$PY	POWER MW	REMARKS
1	AMMONIA	0.0	100000	100000.0	28.606	20.000			1.286	
2	NITROGEN	-669046.6	0	-669046.6				6.690		BY-PRODUCT
3	HYDROGEN	20900.0	0	20900.0	38.979				.498	
4	DD SYNGAS	139214.9	0	139214.9	9.655				3.315	
5	RAW SYNGAS	195875.4	0	195875.4	14.233				4.664	
8	AIR	975048.0	0	975048.0			0.000			RAW MATERIAL
10	WATER	106125.2	0	106125.2			0.000			RAW MATERIAL
11	OXYGEN	176287.8	0	176287.8	14.107				7.555	
12	COAL	101659.3	0	101659.3			4.066			RAW MATERIAL
16	HYDROGEN SULFIDE	-696.1	0	-696.1				.139		BY-PRODUCT
19	CARBON DIOXIDE	-231037.4	0	-231037.4				9.241		BY-PRODUCT
	TOTAL				105.580	20.000	4.066	16.071	17.317	

* CAPITAL COSTS ONLY. NOT INCLUDED ARE OFFSITE FACILITIES, LAND COSTS, AND UTILITIES.

ISOLATED OPERATIONS PRODUCING FORMALDEHYDE

ID	PLANT/MATERIAL	CAPTIVE PRODN. TPY	MERCHANT PRODN. TPY	TOTAL PRODN. TPY	PLANT * COST MM$	PRODUCT VALUE MM$PY	RAW MATL. COST MM$PY	BY-PRODUCT CREDIT MM$PY	POWER MW	REMARKS
2	NITROGEN	-218365.3	0	-218365.3				2.184		BY-PRODUCT
3	HYDROGEN	2363.2	0	2363.2	10.179				.056	
4	DD SYNGAS	39699.4	0	39699.4	3.854				.945	
5	RAW SYNGAS	55857.1	0	55857.1	6.242				1.330	
6	FORMALDEHYDE	0.0	20000	20000.0	3.708	6.000			.476	
7	METHANOL	25140.0	0	25140.0	4.144				.359	
8	AIR	298231.0	0	298231.0			0.000			RAW MATERIAL
10	WATER	16145.8	0	16145.8			0.000			RAW MATERIAL
11	OXYGEN	50271.4	0	50271.4	6.670				2.154	
12	COAL	28989.8	0	28989.8			1.160			RAW MATERIAL
16	HYDROGEN SULFIDE	-198.5	0	-198.5				.040		BY-PRODUCT
19	CARBON DIOXIDE	-31394.2	0	-31394.2				1.256		BY-PRODUCT
	TOTAL				34.796	6.000	1.160	3.479	5.321	

* CAPITAL COSTS ONLY. NOT INCLUDED ARE OFFSITE FACILITIES, LAND COSTS, AND UTILITIES.

ISOLATED OPERATIONS PRODUCING METHANOL

ID	PLANT/MATERIAL	CAPTIVE PRODN. TPY	MERCHANT PRODN. TPY	TOTAL PRODN. TPY	PLANT * COST MM$	PRODUCT VALUE MM$PY	RAW MATL. COST MM$PY	BY-PRODUCT CREDIT MM$PY	POWER MW	REMARKS
2	NITROGEN	-868597.1	0	-868597.1				8.686		BY-PRODUCT
3	HYDROGEN	9400.0	0	9400.0	23.827				.224	
4	DD SYNGAS	157913.4	0	157913.4	10.589				3.760	
5	RAW SYNGAS	222184.2	0	222184.2	15.462				5.290	
7	METHANOL	0.0	100000	100000.0	11.753	22.000			1.429	
8	AIR	1106010.5	0	1106010.5			0.000			RAW MATERIAL
10	WATER	64223.7	0	64223.7			0.000			RAW MATERIAL
11	OXYGEN	199965.7	0	199965.7	15.209				8.570	
12	COAL	115313.6	0	115313.6			4.613			RAW MATERIAL
16	HYDROGEN SULFIDE	-789.6	0	-789.6				.158		BY-PRODUCT
19	CARBON DIOXIDE	-124877.5	0	-124877.5				4.995		BY-PRODUCT
	TOTAL				76.839	22.000	4.613	13.839	19.272	

*CAPITOL COST ONLY. NOT INCLUDED ARE OFFSITE FACILITIES, LAND COSTS, AND UTILITIES.

CO-SITED OPERATIONS (COMPLEX)

ID	PLANT/MATERIAL	CAPTIVE PRODN. TPY	MERCHANT PRODN. TPY	TOTAL PRODN. TPY	PLANT * COST MM$	PRODUCT VALUE MM$PY	RAW MATL. COST MM$PY	BY-PRODUCT CREDIT MM$PY	POWER MW	REMARKS
1	AMMONIA	0.0	100000	100000.0	28.606	20.000			1.286	
2	NITROGEN	-1756009.0	0	-1756009.0				17.560		BY-PRODUCT
3	HYDROGEN	32663.2	0	32663.2	51.319				.778	
4	DD SYNGAS	336827.7	0	336827.7	18.436				8.020	
5	RAW SYNGAS	473916.6	0	473916.6	25.434				11.284	
6	FORMALDEHYDE	0.0	20000	20000.0	3.708	6.000			.476	
7	METHANOL	25140.0	100000	125140.0	13.921	22.000			1.788	
8	AIR	2379289.5	0	2379289.5			0.000			RAW MATERIAL
10	WATER	186494.6	0	186494.6			0.000			RAW MATERIAL
11	OXYGEN	426525.0	0	426525.0	23.906				18.280	
12	COAL	245962.7	0	245962.7			9.839			RAW MATERIAL
16	HYDROGEN SULFIDE	-1684.1	0	-1684.1				.337		BY-PRODUCT
19	CARBON DIOXIDE	-387309.1	0	-387309.1				15.492		BY-PRODUCT
	TOTAL				165.329	48.000	9.839	33.389	41.910	

* CAPITAL COSTS ONLY. NOT INCLUDED ARE OFFSITE FACILITIES, LAND COSTS, AND UTILITIES.

14. DO YOU WISH TO ANALYZE THE SAME COMPLEX BUT WITH
    A DIFFERENT ANNUAL INCREASE IN PLANT COSTS ?

? NO

15A. DO YOU WANT TO PERFORM AN ECONOMIC ANALYSIS FOR
     ANOTHER COMPLEX ?

? YES

15B. DO YOU WANT TO USE THE SAME PLANT-COST BASIS IN
     THIS ANALYSIS YOU CHOSE IN RESPONSE TO
     STATEMENTS 12 AND 13 IN THE PREVIOUS ANALYSIS?

? YES

10. FOR HOW MANY INDUSTRIES IN THE COMPLEX WILL YOU
    SPECIFY MERCHANT CAPACITIES ?

? 4

11. LIST THE CODE NUMBERS OF THE INDUSTRIES IN THE
    COMPLEX AND THEIR MERCHANT CAPACITIES, I.E.,
    INDUSTRY NUMBER, CAPACITY (TONS/YEAR)

? 9, 200000
? 14, 100000
? 15, 10000
? 17, 100000

ISOLATED OPERATIONS PRODUCING GASOLINE

ID	PLANT/MATERIAL	CAPTIVE PRODN. TPY	MERCHANT PRODN. TPY	TOTAL PRODN. TPY	PLANT * COST MM$	PRODUCT VALUE MM$PY	RAW MATL. COST MM$PY	BY-PRODUCT CREDIT MM$PY	POWER MW	REMARKS
2	NITROGEN	-4522688.4	0	-4522688.4				45.227		BY-PRODUCT
3	HYDROGEN	49124.4	0	49124.4	65.987				1.170	
4	DD SYNGAS	825255.4	0	825255.4	35.525				19.649	
5	RAW SYNGAS	1161134.4	0	1161134.4	45.825				27.646	
7	METHANOL	522600.0	0	522600.0	40.960				7.466	
8	AIR	5780010.9	0	5780010.9			0.000			RAW MATERIAL
9	GASOLINE	0.0	200000	200000.0	14.505	80.000			4.762	
10	WATER	335632.8	0	335632.8			0.000			RAW MATERIAL
11	OXYGEN	1045020.9	0	1045020.9	40.818				44.787	
12	COAL	602628.7	0	602628.7			24.105			RAW MATERIAL
16	HYDROGEN SULFIDE	-4126.3	0	-4126.3				.825		BY-PRODUCT
19	CARBON DIOXIDE	-652610.1	0	-652610.1				26.104		BY-PRODUCT
	TOTAL				243.618	80.000	24.105	72.157	105.479	

* CAPITAL COSTS ONLY. NOT INCLUDED ARE OFFSITE FACILITIES, LAND COSTS, AND UTILITIES.

ISOLATED OPERATIONS PRODUCING SNG

ID	PLANT/MATERIAL	CAPTIVE PRODN. TPY	MERCHANT PRODN. TPY	TOTAL PRODN. TPY	PLANT * COST MM$	PRODUCT VALUE MM$PY	RAW MATL. COST MM$PY	BY-PRODUCT CREDIT MM$PY	POWER MW	REMARKS
2	NITROGEN	-2154883.0	0	-2154883.0				21.549		BY-PRODUCT
3	HYDROGEN	35800.0	0	35800.0	54.301				.852	
4	DD SYNGAS	391763.8	0	391763.8	20.591				9.328	
5	RAW SYNGAS	551211.7	0	551211.7	28.088				13.124	
8	AIR	2743876.6	0	2743876.6			0.000			RAW MATERIAL
10	WATER	208314.0	0	208314.0			0.000			RAW MATERIAL
11	OXYGEN	496090.5	0	496090.5	26.163				21.261	
12	COAL	286078.9	0	286078.9			11.443			RAW MATERIAL
14	SNG	0.0	100000	100000.0	19.470	30.000			2.381	
16	HYDROGEN SULFIDE	-1958.8	0	-1958.8				.392		BY-PRODUCT
19	CARBON DIOXIDE	-429474.2	0	-429474.2				17.179		BY-PRODUCT
	TOTAL				148.613	30.000	11.443	39.120	46.946	

* CAPITAL COSTS ONLY. NOT INCLUDED ARE OFFSITE FACILTIES, LAND COSTS, AND UTILITIES.

ISOLATED OPERATIONS PRODUCING SULFUR

ID	PLANT/MATERIAL	CAPTIVE PRODN. TPY	MERCHANT PRODN. TPY	TOTAL PRODN. TPY	PLANT * COST MM$	PRODUCT VALUE MM$PY	RAW MATL. COST MM$PY	BY-PRODUCT CREDIT MM$PY	POWER MW	REMARKS
2	NITROGEN	-5571.8	0	-5571.8				.056		BY-PRODUCT
3	HYDROGEN	152.1	0	152.1	1.878				.004	
4	DD SYNGAS	1013.0	0	1013.0	.263				.024	
5	RAW SYNGAS	1425.2	0	1425.2	.561				.034	
8	AIR	34883.3	0	34883.3			0.000			RAW MATERIAL
10	WATER	772.2	0	772.2			0.000			RAW MATERIAL
11	OXYGEN	1282.7	0	1282.7	.746				.055	
12	COAL	739.7	0	739.7			0.030			RAW MATERIAL
13	CLAUS OFF-GAS	23472.0	0	23472.0			0.000			RAW MATERIAL
15	SULFUR	0.0	10000	10000.0	.825	1.000			.238	
16	HYDROGEN SULFIDE	13824.9	0	13824.9	1.826				0.000	
19	CARBON DIOXIDE	-1681.1	0	-1681.1				.067		BY-PRODUCT
	TOTAL				6.099	1.000	.030	.123	.355	

* CAPITAL COSTS ONLY. NOT INCLUDED ARE OFFSITE FACILITIES, LAND COSTS, AND UTILITIES

ISOLATED OPERATIONS PRODUCTING SULFURIC ACID

ID	PLANT/MATERIAL	CAPTIVE PRODN. TPY	MERCHANT PRODN. TPY	TOTAL PRODN. TPY	PLANT * COST MM$	PRODUCT VALUE MM$PY	RAW MATL. COST MM$PY	BY-PRODUCT CREDIT MM$PY	POWER MW	REMARKS
2	NITROGEN	-19167.0	0	-19167.0				.192		BY-PRODUCT
3	HYDROGEN	523.1	0	523.1	4.021				.012	
4	DD SYNGAS	3484.6	0	3484.6	.649				.083	
5	RAW SYNGAS	4902.8	0	4902.8	1.262				.117	
8	AIR	1025598.4	0	1025598.4			0.000			RAW MATERIAL
10	WATER	21056.4	0	21056.4			0.000			RAW MATERIAL
11	OXYGEN	4412.6	0	4412.6	1.561				.189	
12	COAL	2544.6	0	2544.6			.102			RAW MATERIAL
13	CLAUS OFF-GAS	80743.6	0	80743.6			0.000			RAW MATERIAL
15	SULFUR	34400.0	0	34400.0	1.854				.819	
16	HYDROGEN SULFIDE	47557.8	0	47557.8	4.390				0.000	
17	SULFURIC ACID	0.0	100000	100000.0	13.669	6.000			.060	
19	CARBON DIOXIDE	-5783.0	0	-5783.0				.231		BY-PRODUCT
	TOTAL				27.406	6.000	.102	.423	1.280	

* CAPITAL COSTS ONLY. NOT INCLUDED ARE OFFSITE FACILTIES, LAND COSTS, AND UTILITIES.

CO-SITED OPERATIONS (COMPLEX)

ID	PLANT/MATERIAL	CAPTIVE PRODN. TPY	MERCHANT PRODN. TPY	TOTAL PRODN. TPY	PLANT * COST MM$	PRODUCT VALUE MM$PY	RAW MATL. COST MM$PY	BY-PRODUCT CREDIT MM$PY	POWER MW	REMARKS
2	NITROGEN	-6699858.5	0	-6699858.5				66.999		BY-PRODUCT
3	HYDROGEN	85532.7	0	85532.7	92.856				2.036	
4	DD SYNGAS	1221071.1		1221071.1	47.325				29.073	
5	RAW SYNGAS	1718047.0	0	1718047.0	59.277				40.906	
7	METHANOL	522600.0	0	522600.0	40.960				7.466	
8	AIR	9579945.7	0	9579945.7			0.000			RAW MATERIAL
9	GASOLINE	0.0	200000	200000.0	14.505	80.000			4.762	
10	WATER	565435.6	0	565435.6			0.000			RAW MATERIAL
11	OXYGEN	1546242.3	0	1546242.3	51.574				66.268	
12	COAL	891666.4	0	891666.4			35.667			RAW MATERIAL
13	CLAUS OFF-GAS	81629.9	0	81629.9			0.000			RAW MATERIAL
14	SNG	0.0	100000	100000.0	19.470	30.000			2.381	
15	SULFUR	34400.0	10000	44400.0	2.192	1.000			1.057	
16	HYDROGEN SULFIDE	55299.8	0	55299.8	4.887				0.000	
17	SULFURIC ACID	0.0	100000	100000.0	13.669	6.000			.060	
19	CARBON DIOXIDE	-1088808.7	0	-1088808.7				43.552		BY-PRODUCT
	TOTAL				346.714	117.000	35.667	110.551	154.008	

* CAPITAL COST ONLY. NOT INCLUDED ARE OFFSITE FACILITIES, LAND COSTS, AND UTILITIES.

14. DO YOU WISH TO ANALYZE THE SAME COMPLEX BUT WITH
    A DIFFERENT ANNUAL INCREASE IN PLANT COSTS ?
? NO

15A. DO YOU WNAT TO PERFORM AN ECONOMIC ANALYSIS FOR
    ANOTHER COMPLEX?
? YES

15B. DO YOU WANT TO USE THE SAME PLANT-COST BASIS IN
    THIS ANALYSIS YOU CHOSE IN RESPONSE TO
    STATEMENTS 12 AND 13 IN THE PREVIOUS ANALYSIS?
? YES

10. FOR HOW MANY INDUSTRIES IN THE COMPLEX WILL YOU
    SPECIFY MERCHANT CAPACITIES?
? 7

11. LIST THE CODE NUMBERS OF THE INDUSTRIES IN THE
COMPLEX AND THEIR MERCHANT CAPACITIES, I.E.,
INDUSTRY NUMBER, CAPACITY (TONS/YEAR)

? 1, 100000
? 6, 20000
? 7, 100000
? 9, 200000
? 14, 100000
? 15, 10000
? 17, 100000

ISOLATED OPERATIONS PRODUCING AMMONIA

ID	PLANT/MATERIAL	CAPTIVE PRODN. TPY	MERCHANT PRODN. TPY	TOTAL PRODN. TPY	PLANT * COST MM$	PRODUCT VALUE MM$PY	RAW MATL. COST MM$PY	BY-PRODUCT CREDIT MM$PY	POWER MW	REMARKS
1	AMMONIA	0.0	100000	100000.0	28.606	20.000			1.286	
2	NITROGEN	-669046.6	0	-669046.6				6.690		BY-PRODUCT
3	HYDROGEN	20900.0	0 0	20900.0	38.979				.498	
4	DD SYNGAS	139214.9	0	139214.9	9.655				3.315	
5	RAW SYNGAS	195875.4	0	195875.4	14.233				4.664	
8	AIR	975048.0	0	975048.0			0.000			RAW MATERIAL
10	WATER	106125.2	0	106125.2			0.000			RAW MATERIAL
11	OXYGEN	176287.8	0	176287.8	14.107				7.555	
12	COAL	101659.3	0	101659.3			4.066			RAW MATERIAL
16	HYDROGEN SULFIDE	-696.1	0	-696.1				.139		BY-PRODUCT
19	CARBON DIOXIDE	-231037.4	0	-231037.4				9.241		BY-PRODUCT
	TOTAL				105.580	20.000	4.066	16.071	17.317	

* CAPITAL COSTS ONLY. NOT INCLUDED ARE OFFSITE FACILITIES, LAND COSTS, AND UTILITIES.

ISOLATED OPERATIONS PRODUCING FORMALDEHYDE

ID	PLANT/MATERIAL	CAPTIVE PRODN. TPY	MERCHANT PRODN. TPY	TOTAL PRODN. TPY	PLANT * COST MM$	PRODUCT VALUE MM$PY	RAW MATL. COST MM$PY	BY-PRODUCT CREDIT MM$PY	POWER MW	REMARKS
2	NITROGEN	-218365.3	0	-218365.3				2.184		BY-PRODUCT
3	HYDROGEN	2363.2	0	2363.2	10.179				.056	
4	DD SYNGAS	39699.4	0	39699.4	3.854				.945	
5	RAW SYNGAS	55857.1	0	55857.1	6.242				1.330	
6	FORMALDEHYDE	0.0	20000	20000.0	3.708	6.000			.476	
7	METHANOL	25140.0	0	25140.0	4.144				.359	
8	AIR	298231.0	0	298231.0			0.000			RAW MATERIAL
10	WATER	16145.8	0	16145.8			0.000			RAW MATERIAL
11	OXYGEN	50271.4	0	50271.4	6.670				2.154	
12	COAL	28989.8	0	28989.8			1.160			RAW MATERIAL
16	HYDROGEN SULFIDE	-198.5	0	-198.5				.040		BY-PRODUCT
19	CARBON DIOXIDE	-31394.2	0	-31394.2				1.256		BY-PRODUCT
	TOTAL				34.796	6.000	1.160	3.479	5.321	

* CAPITAL COSTS ONLY. NOT INCLUDED ARE OFFSITE FACILTIES, LAND COSTS, AND UTILITIES.

ISOLATED OPERATIONS PRODUCING METHANOL

ID	PLANT/MATERIAL	CAPTIVE PRODN. TPY	MERCHANT PRODN. TPY	TOTAL PRODN. TPY	PLANT * COST MM$	PRODUCT VALUE MM$PY	RAW MATL. COST MM$PY	BY-PRODUCT CREDIT MM$PY	POWER MW	REMARKS
2	NITROGEN	-868597.1	0	-868597.1				8.686		BY-PRODUCT
3	HYDROGEN	9400.0	0	9400.0	23.827				.224	
4	DD SYNGAS	157913.4	0	157913.4	10.589				3.760	
5	RAW SYNGAS	222184.2	0	222184.2	15.462				5.290	
7	METHANOL	0.0	100000	100000.0	11.753	22.000			1.429	
8	AIR	1106010.5	0	1106010.5			0.000			RAW MATERIAL
10	WATER	64223.7	0	64223.7			0.000			RAW MATERIAL
11	OXYGEN	199965.7	0	199965.7	15.209				8.570	
12	COAL	115313.6	0	115313.6			4.613			RAW MATERIAL
16	HYDROGEN SULFIDE	-789.6	0	-789.6				.158		BY-PRODUCT
19	CARBON DIOXIDE	-124877.5	0	-124877.5				4.995		BY-PRODUCT
	TOTAL				76.839	22.000	4.613	13.839	19.272	

* CAPITAL COSTS ONLY. NOT INCLUDED ARE OFFSITE FACILITIES, LAND COSTS AND UTILITIES.

ISOLATED OPERATIONS PRODUCING GASOLINE

ID	PLANT/MATERIAL	CAPTIVE PRODN. TPY	MERCHANT PRODN. TPY	TOTAL PRODN. TPY	PLANT * COST MM$	PRODUCT VALUE MM$PY	RAW MATL. COST MM$PY	BY-PRODUCT CREDIT MM$PY	POWER MW	REMARKS
2	NITROGEN	-4522688.4	0	-4522688.4				45.227		BY-PRODUCT
3	HYDROGEN	49124.4	0	49124.4	65.987				1.170	
4	DD SYNGAS	825255.4	0	825255.4	35.525				19.649	
5	RAW SYNGAS	1161134.4	0	1161134.4	45.825				27.646	
7	METHANOL	522600.0	0	522600.0	40.960				7.466	
8	AIR	5780010.9	0	5780010.9			0.000			RAW MATERIAL
9	GASOLINE	0.0	200000	200000.0	14.505	80.000			4.762	
10	WATER	335632.8	0	335632.8			0.000			RAW MATERIAL
11	OXYGEN	1045020.9	0	1045020.9	40.818				44.787	
12	COAL	602628.7	0	602628.7			24.105			RAW MATERIAL
16	HYDROGEN SULFIDE	-4126.3	0	-4126.3				.825		BY-PRODUCT
19	CARBON DIOXIDE	-652610.1	0	-652610.1				26.104		BY-PRODUCT
	TOTAL				243.618	80.000	24.105	72.157	105.479	

* CAPITAL COSTS ONLY. NOT INCLUDED ARE OFFSITE FACILITIES, LAND COSTS, AND UTILITIES.

ISOLATED OPERATIONS PRODUCING SNG

ID	PLANT/MATERIAL	CAPTIVE PRODN. TPY	MERCHANT PRODN. TPY	TOTAL PRODN. TPY	PLANT * COST MM$	PRODUCT VALUE MM$PY	RAW MATL. COST MM$PY	BY-PRODUCT CREDIT MM$PY	POWER MW	REMARKS
2	NITROGEN	-2154883.0	0	-2154883.0				21.549		BY-PRODUCT
3	HYDROGEN	35800.0	0	35800.0	54.301				.852	
4	DD SYNGAS	391763.8	0	391763.8	20.591				9.328	
5	RAW SYNGAS	551211.7	0	551211.7	28.088				13.124	
8	AIR	2743876.6	0	2743876.6			0.000			RAW MATERIAL
10	WATER	208314.0	0	208314.0			0.000			RAW MATERIAL
11	OXYGEN	496090.5	0	496090.5	26.163				21.261	
12	COAL	286078.9	0	286078.9			11.443			RAW MATERIAL
14	SNG	0.0	100000	100000.0	19.470	30.000			2.381	
16	HYDROGEN SULFIDE	-1958.8	0	-1958.8				.392		BY-PRODUCT
19	CARBON DIOXIDE	-429474.2	0	-429474.2				17.179		BY-PRODUCT
	TOTAL				148.613	30.000	11.443	39.120	46.946	

* CAPITAL COSTS ONLY. NOT INCLUDED ARE OFFSITE FACILITIES, LAND COSTS, AND UTILITIES.

ISOLATED OPERATIONS PRODUCING SULFUR

ID	PLANT/MATERIAL	CAPTIVE PRODN. TPY	MERCHANT PRODN. TPY	TOTAL PRODN. TPY	PLANT * COST MM$	PRODUCT VALUE MM$PY	RAW MATL. COST MM$PY	BY-PRODUCT CREDIT MM$PY	POWER MW	REMARKS
2	NITROGEN	-5571.8	0	-5571.8				.056		BY-PRODUCT
3	HYDROGEN	152.1	0	152.1	1.878				.004	
4	DD SYNGAS	1013.0	0	1013.0	.263				.024	
5	RAW SYNGAS	1425.2	0	1425.2	.561				.034	
8	AIR	34883.3	0	34883.3			0.000			RAW MATERIAL
10	WATER	772.2	0	772.2			0.000			RAW MATERIAL
11	OXYGEN	1282.7	0	1282.7	.746				.055	
12	COAL	739.7	0	739.7			.030			RAW MATERIAL
13	CLAUS OFF-GAS	23472.0	0	23472.0			0.000			RAW MATERIAL
15	SULFUR	0.0	10000	10000.0	.825	1.000			.238	
16	HYDROGEN SULFIDE	13824.9	0	13824.9	1.826				0.000	
19	CARBON DIOXIDE	-1681.1	0	-1681.1				.067		BY-PRODUCT
	TOTAL				6.099	1.000	.030	.123	.355	

* CAPITAL COSTS ONLY. NOT INCLUDED ARE OFFSITE FACILITIES, LAND COSTS, AND UTILITIES.

ISOLATED OPERATIONS PRODUCING SULFURIC ACID

ID	PLANT/MATERIAL	CAPTIVE PRODN. TPY	MERCHANT PRODN. TPY	TOTAL PRODN. TPY	PLANT * COST MM$	PRODUCT VALUE MM$PY	RAW MATL. COST MM$PY	BY-PRODUCT CREDIT MM$PY	POWER MW	REMARKS
2	NITROGEN	-19167.0	0	-19167.0				.192		BY-PRODUCT
3	HYDROGEN	523.1	0	523.1	4.021				.012	
4	DD SYNGAS	3484.6	0	3484.6	.649				.083	
5	RAW SYNGAS	4902.8	0	4902.8	1.262				.117	
8	AIR	1025598.4	0	1025598.4			0.000			RAW MATERIAL
10	WATER	21056.4	0	21056.4			0.000			RAW MATERIAL
11	OXYGEN	4412.6	0	4412.6	1.561				.189	
12	COAL	2544.6	0	2544.6			.102			RAW MATERIAL
13	CLAUS OFF-GAS	80743.6	0	80743.6			0.000			RAW MATERIAL
15	SULFUR	34400.0	0	34400.0	1.854				.819	
16	HYDROGEN SULFIDE	47557.8	0	47557.8	4.390				0.000	
17	SULFURIC ACID	0.0	100000	100000.0	13.669	6.000			.060	
19	CARBON DIOXIDE	-5783.0	0	-5783.0				.231		BY-PRODUCT
	TOTAL				27.406	6.000	.102	.423	1.280	

* CAPITAL COSTS ONLY. NOT INCLUDED ARE OFFSITE FACILITIES, LAND COSTS, AND UTILITIES.

CO-SITED OPERATIONS (COMPLEX)

ID	PLANT/MATERIAL	CAPTIVE PRODN. TPY	MERCHANT PRODN. TPY	TOTAL PRODN. TPY	PLANT * COST MM$	PRODUCT VALUE MM$PY	RAW MATL. COST MM$PY	BY-PRODUCT CREDIT MM$PY	POWER MW	REMARKS
1	AMMONIA	0.0	100000	100000.0	28.606	20.000			1.286	
2	NITROGEN	-8455189.0	0	-8455189.0				84.552		BY-PRODUCT
3	HYDROGEN	118177.3	0	118177.3	113.318				2.814	
4	DD SYNGAS	1557775.5	0	1557775.5	56.560				37.090	
5	RAW SYNGAS	2191790.1	0	2191790.1	69.563				52.185	
6	FORMALDEHYDE	0.0	20000	20000.0	3.708	6.000			.476	
7	METHANOL	547740.0	100000	647740.0	48.166	22.000			9.253	
8	AIR	11958011.0	0	11958011.0			0.000			RAW MATERIAL
9	GASOLINE	0.0	200000	200000.0	14.505	80.000			4.762	
10	WATER	751836.2	0	751836.2			0.000			RAW MATERIAL
11	OXYGEN	1972611.1	0	1972611.1	59.645				84.540	
12	COAL	1137539.1	0	1137539.1			45.502			RAW MATERIAL
13	CLAUS OFF-GAS	75379.0	0	75379.0			0.000			RAW MATERIAL
14	SNG	0.0	100000	100000.0	19.470	30.000			2.381	
15	SULFUR	34400.0	10000	44400.0	2.192	1.000			1.057	
16	HYDROGEN SULFIDE	53616.3	0	53616.3	4.781				0.000	
17	SULFURIC ACID	0.0	100000	100000.0	13.669	6.000			.060	
19	CARBON DIOXIDE	-1475913.1	0	-1475913.1				59.037		BY-PRODUCT
	TOTAL				434.181	165.000	45.502	143.588	195.904	

* CAPITAL COSTS ONLY. NOT INCLUDED ARE OFFSITE FACILTIES, LAND COSTS, AND UTILITIES.

14. DO YOU WISH TO ANALYZE THE SAME COMPLEX BUT WITH
    A DIFFERENT ANNUAL INCREASE IN PLANT COSTS ?

? NO

15A. DO YOU WANT TO PERFORM AN ECONOMIC ANALYSIS FOR
    ANOTHER COMPLEX ?

? NO

16. WOULD YOU LIKE TO SPECIFY ANOTHER CORE OF
    INDUSTRIES AND BEGIN ANOTHER SEARCH FOR
    CO-SITING CANDIDATES FOR THIS CORE ?

? NO

2.853 CP SECONDS EXECUTION TIME.

/