This report offers a complete information package regarding the current status of the worldwide fertilizer market, including technology, environmental issues, production costs, cash flow analyses, and internal rates of return. This essential industry is experiencing a period of intense international competition, low profit margins, plant consolidation, and restructuring. Moreover, traditional fertilizer importing countries in Asia are building new plants to become self-sufficient in fertilizer supply. The report, in addition to a comprehensive summary, consists of the following sections:

- Section 3 discusses fertilizer types and classification, the benefits and levels of fertilization, raw material sources, industry structure, world and U.S. consumption, production capacities, new project announcements, prices, and an overview of the industry.
- Section 4 compares the various current technologies used in fertilizer production, and summarizes recent patents for new and improved technologies.
- Section 5 updates PEP’s production costs for a new, world-scale nitrogen fertilizer complex consisting of ammonia, nitric acid, ammonium nitrate, urea, and nitrogen solution. The economics of the complex are analyzed for four locations—the U.S. Gulf Coast, Alberta, Canada, Saudi Arabia, and China. Comparisons are made on the basis of cash flows and internal rate of return.
- Section 6 covers a phosphorus fertilizer complex consisting of sulfuric acid, wet process phosphoric acid, monoammonium phosphate, and diammonium phosphate. The plant locations and economic analysis method are the same as those in Section 5.
- Section 7 addresses environmental issues and regulations relating to the production and use of fertilizers in selected countries and the outlook for waste reduction and avoidance.

The report provides timely information that should be of great value to present and future fertilizer producers, international traders, financial institutions, equipment and technology providers, researchers, and engineering contractors.
CONTENTS

GLOSSARY ..................................................................................................................................... xiii

1 INTRODUCTION ............................................................................................................................. 1-1

2 SUMMARY ...................................................................................................................................... 2-1
  COMMERCIAL ASPECTS .............................................................................................................. 2-1
  TECHNICAL ASPECTS .................................................................................................................. 2-1
  Nitrogen Fertilizer Processes ........................................................................................................ 2-2
    Ammonia ........................................................................................................................................ 2-2
    Nitric Acid .................................................................................................................................... 2-3
    Ammonium Nitrate ...................................................................................................................... 2-3
    Urea .............................................................................................................................................. 2-3
    Nitrogen Solution ....................................................................................................................... 2-4
  Phosphorus Fertilizer Processes .................................................................................................... 2-4
    Sulfuric Acid Process .................................................................................................................. 2-4
    Phosphoric Acid ....................................................................................................................... 2-4
    Monoammonium Phosphate ...................................................................................................... 2-5
    Diammonium Phosphate ........................................................................................................... 2-5
  ENVIRONMENTAL ASPECTS ........................................................................................................ 2-5
  ECONOMIC ASPECTS ................................................................................................................... 2-6
  Nitrogen Fertilizers ....................................................................................................................... 2-6
  Phosphorus Fertilizers .................................................................................................................. 2-12

3 INDUSTRY STATUS ...................................................................................................................... 3-1
  FERTILIZER CLASSIFICATION ....................................................................................................... 3-1
  Nitrogen Fertilizers ....................................................................................................................... 3-4
  Phosphate Fertilizers ................................................................................................................... 3-5
  Potassium Fertilizers ................................................................................................................... 3-5
  BENEFITS OF FERTILIZATION ................................................................................................... 3-6
  COMMERCIAL FERTILIZERS ......................................................................................................... 3-6
  Solid Fertilizers ............................................................................................................................ 3-6
  Fluid Fertilizers ............................................................................................................................ 3-8
  RAW MATERIAL SOURCES .......................................................................................................... 3-9
  Nitrogen and Hydrogen ................................................................................................................. 3-9
  Phosphate Rock ............................................................................................................................ 3-9
  Sulfur ............................................................................................................................................ 3-10
CONTENTS (Continued)

4 TECHNOLOGY (Concluded)
Product Chains.................................................................4-17
H₂SO₄ Production............................................................4-17
Ordinary Superphosphate Production.................................4-18
Triple Superphosphate Production........................................4-19
Thermal P₂O₅ Production....................................................4-19
Wet Process P₂O₅ Production..............................................4-20
Hemihydrate Processes......................................................4-22
Superphosphoric Acid Production........................................4-26
MAP/DAP Production.........................................................4-27

5 NITROGEN FERTILIZER COMPLEX ECONOMICS........5-1
COMPLEX CONFIGURATION...........................................5-1
PROCESS DESCRIPTIONS...............................................5-1
Ammonia Process............................................................5-1
Nitric Acid Process..........................................................5-2
Ammonium Nitrate Process................................................5-2
Urea Process.................................................................5-3
PRODUCTION COST ESTIMATES......................................5-6
INTERNAL RATE OF RETURN..........................................5-46
IRR Calculation Bases.......................................................5-46
IRR Calculation Results....................................................5-47

6 PHOSPHORUS FERTILIZER COMPLEX ECONOMICS......6-1
COMPLEX CONFIGURATION...........................................6-1
PROCESS DESCRIPTION................................................6-1
Sulfuric Acid Process.......................................................6-1
Phosphoric Acid Process..................................................6-2
Monoammonium Phosphate Process....................................6-2
Diammonium Phosphate Process........................................6-3
COST ESTIMATE BASES................................................6-3
PRODUCTION COSTS.......................................................6-4
INTERNAL RATE OF RETURN..........................................6-41
CONCLUSIONS..............................................................6-44
CONTENTS (Concluded)

7 ENVIRONMENTAL ISSUES ..................................................................................................... 7-1
    WASTE STREAMS FROM FERTILIZER MANUFACTURE .................................................. 7-1
    Air Emissions .................................................................................................................. 7-4
    Wastewater Effluents ...................................................................................................... 7-4
    Solid Wastes .................................................................................................................. 7-4

REGULATORY STANDARDS ................................................................................................. 7-6
    Environmental Regulations of Selected Countries ......................................................... 7-7
    Environmental Regulations for U.S. Fertilizer Plants .................................................... 7-13

ENVIRONMENTAL IMPACTS OF FERTILIZER USE ............................................................ 7-13
    Nitrate Contamination of Underground water ................................................................. 7-13
    Increase of Nutrient Levels in Rivers, Lakes, and Reservoirs ....................................... 7-17
    Contamination of Agricultural Soils by Heavy Metals .................................................... 7-17

COSTS .................................................................................................................................. 7-18
    ISO 14001 STANDARDS SERIES .................................................................................. 7-18

CONCLUDING ENVIRONMENTAL OVERVIEW .................................................................... 7-19

APPENDIXES

A PATENT SUMMARY TABLE
B CAPACITIES OF NEW AND REVAMPED FERTILIZER PLANTS
C CASH FLOWS AND IRRs
D DESIGN AND COST BASES
E CITED REFERENCES
F PROCESS FLOW DIAGRAMS
FIGURES

2.1 IRR versus Realization Price of NH₃ .................................................................2-10
2.2 IRR versus Realization Price of AN .................................................................2-10
2.3 IRR versus Realization Price of Urea ...............................................................2-11
2.4 IRR versus Realization Price of N Solution ......................................................2-11
2.5 IRR versus Realization Price of WPPA (P₂O₅ Basis) ........................................2-15
2.6 IRR versus Realization Price of MAP ...............................................................2-15
2.7 IRR versus Realization Price of DAP ...............................................................2-16
3.1 Fertilizer Ingredients Product Chains .................................................................3-2
3.2 Market Shares of Important Product forms ......................................................3-8
3.3 U.S. and World Primary Nutrient Consumption ..............................................3-13
3.4 Population and Grain Yield Trendlines ............................................................3-13
3.5 Benefit of Fertilizer Use versus Product Value and Cost ..................................3-14
3.6 Announced New and Revamp NH₃ and Urea Capacities by World Region, 1996-1998 .................................................................3-25
3.7 International NH₃ Price Trends ........................................................................3-27
3.8 AN Price Trends in Canada and on the U.S. Gulf Coast ......................................3-27
3.9 International Urea Price Trends .......................................................................3-28
3.10 International Ammonium Phosphate Price Trends ............................................3-28
4.1 N Fertilizer Process Chain ............................................................................ F-3
4.2 Kellogg Improved NH₃ Process ........................................................................ F-5
4.3 Uhde Medium-Pressure HNO₃ Process ............................................................ F-7
4.4 Grand-Paroisse Dual-Pressure HNO₃ Process ................................................ F-9
4.5 Snamprojetti Thermal Stripping Process for Urea Production ......................... F-11
4.6 Stamicarbon CO₂ Stripping Process for Urea Production ................................ F-13
4.7 P Fertilizer Process Chain ............................................................................. F-15
4.8 H₂SO₄ from S by the Monsanto Double Absorption Process ........................... F-17
4.9 WPPA by Raytheon Technology ..................................................................... F-19
5.1 N Fertilizer Complex Product Slate .............................................................. F-21
5.2 TVA-Style Continuous Urea-AN Solution Mixing System ............................. 5-4
5.3 NH₃ Production Costs by Plant Location .......................................................5-42
5.4 HNO₃ Production Costs by Plant Location ......................................................5-42
5.5 AN Production Costs by Plant Location ..........................................................5-43
5.6 Urea Production Costs by Plant Location ........................................................5-43
5.7 N Fertilizer Production Costs, U.S. Gulf Coast Location Effect of Operating Level on Production Cost ..........................5-44
FIGURES (Concluded)

5.8 N Fertilizer Production Costs, Alberta, Canada Location
Effect of Operating Level on Production Cost ............................................................5-44

5.9 N Fertilizer Production Costs, Saudi Arabia Location
Effect of Operating Level on Production Cost ............................................................5-45

5.10 N Fertilizer Production Costs, Behai, China Location
Effect of Operating Level on Production Cost ............................................................5-45

5.11 IRR versus Realization Price of N Fertilizers, U.S. Gulf Coast Location ..............5-50

5.12 IRR versus Realization Price of N Fertilizers, Alberta, Canada Location ..............5-50

5.13 IRR versus Realization Price of N Fertilizers, Saudi Arabia Location ....................5-51

5.14 IRR versus Realization Price of N Fertilizers, Behai, China Location....................5-51

5.15 IRR versus Realization Price of NH₃.................................................................5-52

5.16 IRR versus Realization Price of AN.................................................................5-52

5.17 IRR versus Realization Price of Urea..............................................................5-53

5.18 IRR versus Realization Price of N Solution......................................................5-53

6.1 P Fertilizer Complex Product Slate ........................................................................F-23

6.2 WPPA Production Costs by Plant Location .........................................................6-37

6.3 MAP Production Costs by Plant Location .............................................................6-38

6.4 DAP Production Costs by Plant Location .............................................................6-38

6.5 P Fertilizer Production Costs, U.S. Gulf Coast Location
Effect of Operating Level on Production Cost ............................................................6-39

6.6 P Fertilizer Production Costs, Alberta, Canada Location
Effect of Operating Level on Production Cost ............................................................6-40

6.7 P Fertilizer Production Costs, Saudi Arabia Location
Effect of Operating Level on Production Cost ............................................................6-40

6.8 P Fertilizer Production Costs, Behai, China Location
Effect of Operating Level on Production Cost ............................................................6-41

6.9 IRR versus Realization Price of WPPA (P₂O₅ Basis) .............................................6-42

6.10 IRR versus Realization Price of MAP .................................................................6-43

6.11 IRR versus Realization Price of DAP .................................................................6-43

7.1 Fertilizer Production Input-Output ........................................................................F-25
| TABLES |
|-----------------|-----------------|-----------------|-----------------|
| 2.1  | Summary of N Fertilizer Production Costs | 2-7 |
| 2.2  | Summary of P Fertilizer Production Costs | 2-13 |
| 3.1  | Fertilizer Components and N-P-K Contents | 3-3 |
| 3.2  | Fertilizer Name Abbreviations and Typical Grades | 3-4 |
| 3.3  | Solid Single Component Fertilizers and Characteristics | 3-7 |
| 3.4  | World Fertilizer Situation | 3-12 |
| 3.5  | The U.S. Fertilizer Situation | 3-12 |
| 3.6  | World N-P-K Fertilizer Capacities | 3-16 |
| 3.7  | World Capacities of Selected Agricultural N Products | 3-17 |
| 3.8  | World Capacities of Selected Agricultural P Products | 3-18 |
| 3.9  | U.S. Capacities of Major Agricultural N Products | 3-19 |
| 3.10 | U.S. Capacities of Selected Agricultural P Products | 3-19 |
| 3.11 | U.S. Potash Fertilizer Direct Application by Product Type | 3-20 |
| 3.12 | Worldwide Fertilizer Project Announcements | 3.21 |
| 3.13 | New and Revamped Fertilizer Capacity by Region/Country and Product Type | B-3 |
| 3.14 | Prices of Fertilizer and Raw Materials | 3-30 |
| 4.1  | NH₃ Production Technologies | 4-8 |
| 4.2  | Fertilizer Technology Patent Summary | A-3 |
| 4.3  | Comparison of WPPA Options | 4-24 |
| 4.4  | Comparison of Dihydrate and HH WPPA Production | 4-26 |
| 5.1  | Summary of Cost Estimate Bases | 5-5 |
| 5.2  | NH₃ from Natural Gas by KAAP, U.S. Gulf Coast Location Production Costs | 5-8 |
| 5.3  | HNO₃ from NH₃ by Catalytic Oxidation, U.S. Gulf Coast Location Production Costs | 5-10 |
| 5.4  | AN from NH₃ and HNO₃ by a Loop Reactor Process, U.S. Gulf Coast Location Production Costs | 5-12 |
| 5.5  | Urea from NH₃ by the Stamicarbon Process, U.S. Gulf Coast Location Production Costs | 5-14 |
| 5.6  | NH₃ from Natural Gas by KAAP, Alberta, Canada Location Production Costs | 5-16 |
| 5.7  | HNO₃ from NH₃ by Catalytic Oxidation, Alberta, Canada Location Production Costs | 5-18 |
| 5.8  | AN from NH₃ and HNO₃ by a Loop Reactor Process, Alberta, Canada Location Production Costs | 5-20 |
TABLES (Continued)

5.9 Urea from NH₃ by the Stamicarbon Process, Alberta, Canada Location
Production Costs........................................................................................................5-22

5.10 NH₃ from Natural Gas by KAAP, Saudi Arabia Location
Production Costs........................................................................................................5-24

5.11 HNO₃ from NH₃ by Catalytic Oxidation ,Saudi Arabia Location
Production Costs........................................................................................................5-26

5.12 AN from NH₃ and HNO₃ by a Loop Reactor Process, Saudi Arabia Location
Production Costs........................................................................................................5-28

5.13 Urea from NH₃ by the Stamicarbon Process, Saudi Arabia Location
Production Costs........................................................................................................5-30

5.14 NH₃ from Natural Gas by KAAP, Behai, China Location
Production Costs........................................................................................................5-32

5.15 HNO₃ from NH₃ by Catalytic Oxidation, Behai, China Location
Production Costs........................................................................................................5-34

5.16 AN from NH₃ by Catalytic Oxidation, Behai, China Location
Production Costs........................................................................................................5-36

5.17 Urea from NH₃ by the Stamicarbon Process, Behai, China Location
Production Costs........................................................................................................5-38

5.18 IRR Calculation Model Bases.....................................................................................5-47

5.19 N Fertilizer Cash Flows and IRRs, U.S. Gulf Coast Location.......................................C-3

5.20 N Fertilizer Cash Flows and IRRs, Alberta, Canada Location.....................................C-8

5.21 N Fertilizer Cash Flows and IRRs, Saudi Arabia Location........................................C-13

5.22 N Fertilizer Cash Flows and IRRs, Behai, China Location..........................................C-18

5.23 Summary of IRRs of N Fertilizers ..............................................................................5-49

6.1 H₂SO₄ from S, U.S. Gulf Coast Location
Production Costs........................................................................................................6-5

6.2 WPPA by the HH Process, U.S. Gulf Coast Location
Production Costs........................................................................................................6-7

6.3 MAP (11-54-0), Granulated, U.S. Gulf Coast Location
Production Costs........................................................................................................6-9

6.4 DAP (18-46-0), Granulated, U.S. Gulf Coast Location
Production Costs........................................................................................................6-11

6.5 H₂SO₄ from S, Alberta, Canada Location
Production Costs........................................................................................................6-13

6.6 WPPA by the HH Process, Alberta, Canada Location
Production Costs........................................................................................................6-15

6.7 MAP (11-54-0), Granulated, Alberta, Canada Location
Production Costs........................................................................................................6-17

6.8 DAP (18-46-0), Granulated, Alberta, Canada Location
Production Costs........................................................................................................6-19
TABLES (Concluded)

6.9  H₂SO₄ from S, Saudi Arabia Location
Production Costs........................................................................................................6-21

6.10 WPPA by the HH Process, Saudi Arabia Location
Production Costs........................................................................................................6-23

6.11 MAP (11-54-0), Granulated, Saudi Arabia Location
Production Costs........................................................................................................6-25

6.12 DAP (18-46-0), Granulated, Saudi Arabia Location
Production Costs........................................................................................................6-27

6.13 H₂SO₄ from S, Behai, China Location
Production Costs........................................................................................................6-29

6.14 WPPA by the HH Process, Behai, China Location
Production Costs........................................................................................................6-31

6.15 MAP (11-54-0), Granulated, Behai, China Location
Production Costs........................................................................................................6-33

6.16 DAP (11-54-0), Granulated, Behai, China Location
Production Costs........................................................................................................6-35

6.17 P Fertilizer Cash Flows and IRRs, U.S. Gulf Coast Location.........................C-22

6.18 P Fertilizer Cash Flows and IRRs, Alberta, Canada Location..................C-26

6.19 P Fertilizer Cash Flows and IRRs, Saudi Arabia Location .........................C-30

6.20 P Fertilizer Cash Flows and IRRs, Behai, China Location .......................C-34

6.21 Summary of IRRs for P Fertilizers ..............................................................6-44

7.1 Summary of the Characteristics of Waste Streams in Fertilizer Production Plants ...... 7-2

7.2 Chemical Composition of Florida Phosphogypsum ................................................. 7-5

7.3 Air Emission Limits for Existing HNO₃ Plants of Selected Countries .................. 7-8

7.4 Air Emission Limits for New HNO₃ Plants of Selected Countries ....................... 7-8

7.5 H₂SO₄ Air Emission Guidelines of Selected Countries ........................................... 7-9

7.6 Air Emission and Wastewater Discharge Limitations for the European Fertilizer Industry .................................................................7-10

7.7 Air Emission and Wastewater Discharge Standards in India (for Plants Commissioned after 1 January 1982) ..........................................................7-14

7.8 EPA Air Emission Standards for the Fertilizer Industry .........................................7-15

7.9 U.S. Wastewater Effluent Standards for New Fertilizer Plants .........................7-16