

Routes to Propylene
97/98S3

February 2000

TABLE OF CONTENTS

	Page
I EXECUTIVE SUMMARY	1
A. INTRODUCTION	1
B. SECONDARY PROPYLENE PRODUCTION TECHNOLOGIES	2
1. Olefin Metathesis	2
2. Selective C ₄ /C ₅ Cracking	5
C. ECONOMICS	7
D. GLOBAL SUPPLY/DEMAND OUTLOOK	9
1. Demand	9
2. Supply	10
3. Supply/Demand and Trade Balance	11
II CONVENTIONAL TECHNOLOGY	12
A. STEAM CRACKER COPRODUCT	12
B. RECOVERY FROM REFINERY STREAMS	14
1. Introduction	14
2. Process Design	16
C. PROPANE DEHYDROGENATION	18
1. Introduction	18
2. Chemistry	19
3. Process Design	21
(a) UOP Oleflex Process	21
(b) Lummus Catofin Process	28
(c) Linde PDH Process (with BASF)	31
(d) Snamprogetti/Yarsintez FBD Process	32
(e) Phillips STAR Process (Krupp Uhde)	36
III SECONDARY PROPYLENE PRODUCTION TECHNOLOGY	40
A. OLEFIN METATHESIS	40
1. Introduction	40
2. Chemistry	42
3. Process Design	47
(a) Lummus Olefin Conversion Technology	48
(b) IFP-CPC Meta-4 Technology	53

TABLE OF CONTENTS (Continued)

	Page
B. PROPYLENE VIA SELECTIVE C ₄ /C ₅ CRACKING	57
1. Introduction	57
2. Chemistry	58
3. Process Design	59
(a) Mobil Olefin Interconversion (MOI) Technology	60
(b) KBR SUPERFLEXSM Technology	63
C. DEEP CATALYTIC CRACKING (DCC) PROCESS	65
1. Introduction	65
2. Catalysts and Operating Conditions	66
3. Process Design	69
IV ECONOMIC ANALYSIS	74
A. PRICING BASIS	74
1. Raw Materials and Utilities	74
2. Capital Costs	75
B. RECOVERY FROM REFINERY STREAMS	75
C. PROPANE DEHYDROGENATION	77
D. SECONDARY PROPYLENE PRODUCTION TECHNOLOGIES	80
1. Base Case and Analysis Methodology	80
(a) Analysis Methodology	80
(b) Base Case	81
2. Olefin Metathesis	82
3. Selective C ₄ /C ₅ Cracking	89
4. Comparison of Olefin Metathesis versus Selective C ₄ /C ₅ Cracking	94
E. OVERVIEW – PROCESS SELECTION CRITERIA	99
V COMMERCIAL STATUS	102
A. GLOBAL	102
1. Demand	102
2. Supply	103
3. Supply/Demand and Trade Balance	104

**TABLE OF CONTENTS
(Continued)**

	Page
B. UNITED STATES	105
1. Demand	105
2. Supply	107
(a) Production Capability	107
(b) Steam Cracker Propylene Production	114
(c) Refinery Propylene Production	115
3. Supply/Demand and Trade Balance	115
C. WESTERN EUROPE	117
1. Demand	117
2. Supply	120
(a) Steam Cracker Propylene Production	123
(b) Refinery Propylene Production	124
(c) Propane Dehydrogenation Propylene Production	125
(d) Metathesis Propylene Production	126
3. Supply/Demand and Trade Balance	126
D. JAPAN AND EAST ASIA	127
1. Demand	127
2. Supply	131
3. Supply/Demand and Trade Balance	133
 REFERENCES	 135
 APPENDIX	 136
 PERP TITLE INDEX	 141

TABLES

	Page	
Table I.B.1	Metathesis Process Characteristics	4
Table I.B.2	Selective C ₄ /C ₅ Cracking Technology Process Characteristics	6
Table I.C.1	Comparative Economics of Secondary Propylene Processes	7
Table I.C.2	Secondary Propylene Process Selection Matrix	8
Table I.D.1	Global Propylene Consumption	9
Table I.D.2	Global Propylene Capacity	11
Table I.D.3	Global Propylene Supply/Demand Balance	11
Table II.A.1	Chemical Grade Propylene Yield from Representative Cracker Feedstocks	12
Table II.A.2	Impact of Feedstock and Flexibility on Investment Cost	14
Table II.B.1	Propylene Product Specifications	15
Table II.B.2	Fractionation Column Design Parameters for Chemical and Polymer Grade Propylene	16
Table II.C.1	Propane Dehydrogenation Capacity, 1997/98	18
Table II.C.2	Propane Dehydrogenation Process Characteristics	22
Table II.C.3	Propane Dehydrogenation Material Balance	27
Table II.C.4	STAR Dehydrogenation Process Conditions	38
Table III.A.1	Maximizing Ethylene and Propylene with Metathesis	41
Table III.A.2	Metathesis Process Characteristics	47
Table III.A.3	Representative C ₄ Stream Compositions	48
Table III.A.4	Material Balance Comparison for Steam Cracker and Steam Cracker with Lummus OCU	50
Table III.A.5	Material Balance for Lummus Olefins Conversion Unit	51
Table III.A.6	Material Balance for the IFP Metathesis Process	57
Table III.B.1	Selective C ₄ /C ₅ Cracking Technology Process Characteristics	59
Table III.B.2	Representative C ₅ Stream Compositions	60
Table III.C.1	DCC Capacity, 1997/98	66
Table III.C.2	DCC Product Slate and Olefin Yield	67
Table III.C.3	DCC Type 1 and FCC Design Operating Conditions	68
Table III.C.4	DCC Feed Analysis at TPI	72
Table III.C.5	Operating Conditions at TPI	72
Table III.C.6	Pilot Plant and Commercial Plant Data for TPI	73

**TABLES
(Continued)**

		Page
Table IV.A.1	Raw Material and Byproduct Prices	74
Table IV.A.2	Utility Prices and Labor Rates	75
Table IV.B.1	Cost of Production Estimate for: Polymer Grade Propylene Process: Refinery Propylene Fractionation	76
Table IV.C.1	Cost of Production Estimate for: Polymer Grade Propylene Process: Oleflex Propane Dehydrogenation	78
Table IV.D.1	Cost of Production Estimate for: Ethylene with Selective Hydrogenation of Butadiene Process: Light Naphtha Cracker (Moderate Severity)	84
Table IV.D.2	Cost of Production Estimate for: Ethylene with Selective Hydrogenation of Butadiene and Metathesis Process: Light Naphtha Cracker (Moderate Severity) + Lummus Metathesis	86
Table IV.D.3	ROI of Base Cracker with Olefin Metathesis and on an Incremental Basis	88
Table IV.D.4	Cost of Production Estimate for: Ethylene with Selective Hydrogenation of Butadiene and Superflex Process: Light Naphtha Cracker (Moderate Severity) + Superflex	92
Table IV.D.5	ROI of Base Cracker with Selective C4/C5 Cracking and on an Incremental Basis	93
Table IV.D.6	Material Balance Summary Cracker Feed of 5.3 Billion Pounds per Year Naphtha	94
Table IV.E.1	Comparative Economics of Secondary Propylene processes	100
Table IV.E.2	Secondary Propylene Process Selection Matrix	101
Table V.A.1	Global Propylene Consumption	102
Table V.A.2	Global Propylene Capacity	104
Table V.A.3	Global Propylene Supply/Demand Balance	104
Table V.B.1	U.S. Propylene Consumption by Derivative	105
Table V.B.2	U.S. Propylene Consumption by Derivative	106
Table V.B.3	U.S. Propylene Production Capability	109-111
Table V.B.4	U.S. Propylene Production Capability	112-114

**TABLES
(Continued)**

		Page
Table V.B.5	U.S. Propylene Supply/Demand and Trade Balance	116
Table V.B.6	U.S. Propylene Supply/Demand and Trade Balance	116
Table V.B.7	U.S. Propylene Supply and Demand	117
Table V.B.8	U.S. Propylene Supply and Demand	117
Table V.C.1	West European Propylene Consumption by Country, 1998	118
Table V.C.2	West European Propylene Consumption by Derivative	119
Table V.C.3	West European Propylene Production by Capability	121-123
Table V.C.4	West European Propylene Supply/Demand and Trade Balance	126
Table V.C.5	West European Propylene Supply and Demand	127
Table V.D.1	Japanese Propylene Consumption by Derivative	128
Table V.D.2	East Asian Propylene Consumption by Country	130
Table V.D.3	Japanese Propylene Production Capability	132
Table V.D.4	East Asian Propylene Production Capability	133
Table V.D.5	Japanese Propylene Supply/Demand and Trade Balance	133
Table V.D.6	East Asian Propylene Supply/Demand and Trade Balance	134

FIGURES

		Page
Figure I.D.1	Global Propylene Consumption by Region	10
Figure II.B.1	Refinery Propylene Upgrading Process Flow Diagram	17
Figure II.C.1	Paraffin Dehydrogenation Thermodynamic Conversion at 1.0 Bara	20
Figure II.C.2	Oleflex Propane Dehydrogenation Simplified Flow Diagram	23
Figure II.C.3	Oleflex Catalyst Regeneration Simplified Flow Diagram	26
Figure II.C.4	Catofin Propane Dehydrogenation Simplified Flow Diagram	30
Figure II.C.5	Linde/BASF Propane Dehydrogenation Simplified Flow Diagram	33
Figure II.C.6	Snamprogetti/Yarsintez FBD Propane Dehydrogenation Simplified Flow Diagram	35
Figure II.C.7	Phillips' Star Propane Dehydrogenation Simplified Flow Diagram	37
Figure III.A.1	Steam Cracker Integrated with Enhanced Propylene Production Unit	43
Figure III.A.2	Simplified Flow Diagram for Propylene via Metathesis (Lummus)	52
Figure III.A.3	Simplified Flow Diagram for Propylene via Metathesis (IFP)	56
Figure III.B.1	Simplified Flow Diagram for Mobil Olefin Interconversion (MOI)	62
Figure III.B.2	Simplified Flow Diagram for KBR - Superflex	64
Figure III.C.1	DCC Simplified Process Flow Diagram	70
Figure IV.B.1	Polymer Grade Propylene Premiums Relative to Refinery Grade Propylene	77
Figure IV.C.1	Sensitivity of Propylene Cost via Propane Dehydrogenation to Propane Price	79
Figure IV.C.2	Polymer Grade Propylene Premiums Relative to Propane	80
Figure IV.D.1	Material Balance for Base Cracker	83
Figure IV.D.2	Material Balance for Cracker with Metathesis	85
Figure IV.D.3	Material Balance for Cracker with MOI	90
Figure IV.D.4	Material Balance for Cracker with Superflex	91
Figure IV.D.5	Sensitivity of Olefin Metathesis and Selective C ₄ /C ₅ Cracking Economics on P/E Price Ratio	96
Figure IV.D.6	Historical Ethylene and Propylene Pricing	97

**FIGURES
(Continued)**

	Page
Figure IV.D.7 West European Historical Ethylene and Propylene Pricing	97
Figure IV.D.8 Korean (Ulsan) Historical Ethylene and Propylene Pricing	98
Figure IV.D.9 Historical P/E Ratio	98
Figure V.A.1 Global Propylene Consumption by Region	103
Figure V.B.1 U.S. Propylene Consumption by Derivative	107
Figure V.C.1 West European Propylene Consumption by Derivative	120
Figure V.D.1 Japanese Propylene Consumption by Derivative	129
Figure V.D.2 East Asian Propylene Consumption by Country	130