

PERP Report

Alpha Olefins

06/07-5

April 2008



44 South Broadway, White Plains, New York 10601, USA
Tel: +1 914 609 0300 Fax: +1 914 609 0399

Copyright© by Nexant, Inc. 2008

This report was prepared by Nexant, Inc ("Nexant") and is part of the Process Evaluation Research Planning (PERP). Except where specifically stated otherwise in this Report, the information contained herein is prepared on the basis of information that is publicly available, and contains no confidential third party technical information to the best knowledge of Nexant. Aforesaid information has not been independently verified or otherwise examined to determine its accuracy, completeness or financial feasibility.

Neither NEXANT, Subscriber nor any person acting on behalf of either assumes any liabilities with respect to the use of or for damages resulting from the use of any information contained in this Report. Nexant does not represent or warrant that any assumed conditions will come to pass.

The report is submitted on the understanding that the Subscriber will maintain the contents confidential except for the Subscriber's internal use. The Report should not be reproduced, distributed or used without first obtaining prior written consent by Nexant. Each Subscriber agrees to use reasonable effort to protect the confidential nature of the Report.

Contents

Section	Page
1 Summary	1
1.1 OVERVIEW OF ALPHA OLEFINS	1
1.1.1 The Business	1
1.1.2 The Technology	2
1.2 COMMERCIAL FULL-RANGE TECHNOLOGY	3
1.2.1 Chevron Phillips.....	3
1.2.2 Shell	4
1.2.3 INEOS (Formerly BP)	6
1.2.4 Idemitsu.....	7
1.3 COMMERCIAL SINGLE-FRACTION TECHNOLOGY	7
1.3.1 Commercial Technologies for Butene-1	7
1.3.2 Commercial Technologies for On-Purpose Hexene-1	8
1.3.3 Commercial Technology for On-Purpose Octene-1	11
1.4 NEW FULL-RANGE TECHNOLOGIES	14
1.4.1 AXENS ALPHASELECT®	14
1.4.2 UOP Linear-1® Process.....	15
1.4.3 SABIC/LINDE ALPHA-SABLIN®	16
1.5 EMERGING ON-PURPOSE TECHNOLOGY	18
1.5.1 Lummus On-Purpose Hexene-1 Process	18
1.5.2 Dow Butadiene-Based Octene-1 Process.....	19
1.5.3 Sasol Ethylene Tetramerization for Octene-1	20
1.5.4 Sasol Heptene-1 to Octene-1 Process	21
1.6 ECONOMICS	22
1.6.1 Commercial Full-Range Process.....	22
1.6.2 Commercial On-Purpose Processes	23
1.6.3 On-Purpose Hexene-1 Process Comparison	24
1.6.4 On-Purpose Octene-1 Process Comparison	25
1.7 GLOBAL MARKET OUTLOOK	26
1.7.1 Demand	26

1.7.2	Supply	27
1.7.3	Global Trade	29
2	Introduction	30
2.1	OVERVIEW OF ALPHA OLEFINS	30
2.1.1	The Business	30
2.1.2	The Technology	31
2.2	FULL-RANGE ALPHA OLEFIN CHEMISTRY	32
2.2.1	Introduction	32
2.3	REVIEW OF RECENT LAO PROCESS PATENTS	39
3	Commercial Full-Range Technology	42
3.1	OVERVIEW	42
3.2	CHEVRON PHILLIPS	42
3.2.1	Process Chemistry	42
3.2.2	Process Description	43
3.2.3	Typical Product Spectrum	46
3.3	SHELL	47
3.3.1	Process Chemistry	47
3.3.2	Process Description	49
3.3.3	Product Spectrum	56
3.4	INEOS (FORMERLY BP)	58
3.4.1	Overview	58
3.4.2	Process Description	58
3.4.3	Product Distribution	60
3.5	IDEMITSU	61
3.5.1	Process Chemistry	61
3.5.2	Process Description	62
4	Commercial Single-Fraction Technology	66
4.1	COMMERCIAL TECHNOLOGIES FOR BUTENE-1	66
4.1.1	Feedstock Issues	66
4.1.2	Nippon Zeon Extractive Distillation	67
4.1.3	ALPHABUTOL [®] (Ethylene Dimerization)	68

4.2	COMMERCIAL TECHNOLOGIES FOR ON-PURPOSE HEXENE-1	72
4.2.1	Sasol Fischer Tropsch-Derived Hexene-1	72
4.2.2	Chevron Phillips Ethylene Trimerization to Hexene-1	79
4.3	COMMERCIAL TECHNOLOGY FOR ON-PURPOSE OCTENE-1	82
4.3.1	Sasol Fischer Tropsch-Derived Octene-1	82
5	New Full-Range Technologies	89
5.1	AXENS ALPHASELECT®	89
5.1.1	Process Chemistry	89
5.1.2	Process Design	90
5.2	UOP LINEAR-1® PROCESS	92
5.2.1	Process Chemistry	92
5.2.2	Process Design	93
5.3	SABIC/LINDE ALPHA-SABLIN®	96
5.3.1	Background	96
5.3.2	Process Chemistry	96
5.3.3	Process Design	97
6	Emerging On-Purpose Technology	100
6.1	LUMMUS ON-PURPOSE HEXENE-1 PROCESS	100
6.1.1	Process Chemistry	100
6.1.2	Process Description	102
6.1.3	Campaign Mode CPT	104
6.2	DOW BUTADIENE-BASED OCTENE-1 PROCESS	105
6.2.1	Telomerization	105
6.2.2	Hydrogenation of 1-Methoxy-2,7-Octadiene	106
6.2.3	Cracking 1-Methoxyoctane to Octene-1	106
6.2.4	Process Description	107
6.3	SASOL ETHYLENE TETRAMERIZATION FOR OCTENE-1	110
6.4	SASOL HEPTENE-1 TO OCTENE-1 PROCESS	114
7	Economic Analysis	120
7.1	BASES	120
7.1.1	Pricing Basis	120

7.1.2	Investment Basis	121
7.1.3	Cost of Production Basis.....	121
7.2	COMMERCIAL FULL-RANGE PROCESSES	122
7.2.1	Chevron Phillips.....	122
7.2.2	INEOS.....	122
7.2.3	Shell Alpha Olefins with Metathesis	125
7.2.4	Idemitsu Technology	125
7.2.5	Cost Comparison.....	125
7.3	COMMERCIAL ON-PURPOSE TECHNOLOGY	129
7.3.1	On-Purpose Hexene-1	129
7.3.2	On-Purpose Octene-1	129
7.3.3	On-Purpose Butene-1	129
7.3.4	Cost Comparisons	135
	NEW ON-PURPOSE TECHNOLOGY	137
7.3.5	Lummus On-Purpose Hexene-1 via Butene-1 Auto-Metathesis (CPT)	137
7.3.6	Dow Butadiene Telomerization On-Purpose Octene-1 Process	137
7.3.7	Sasol On-Purpose Octene-1/Hexene-1 via Ethylene Tetramerization	140
7.3.8	Sasol Heptene-1 Based Process to Octene-1	140
7.3.9	On-Purpose Cost Comparisons	143
8	Commercial Analysis	145
8.1	OVERVIEW	145
8.2	ALPHA OLEFIN APPLICATIONS REVIEW	145
8.2.1	Polyolefins	145
8.2.2	Poly Alpha Olefins.....	148
8.2.3	Detergent Intermediates	149
8.2.4	Linear Plasticizer Alcohols	151
8.2.5	Other Applications	152
8.3	GLOBAL MARKET OUTLOOK	154
8.3.1	Demand	154
8.3.2	Supply	155
8.3.3	Global Trade	157

8.4	NORTH AMERICA	158
8.5	WESTERN EUROPE	161
8.6	JAPAN	163
8.7	EAST ASIA	165

Appendix		Page
A	Capital Cost Assessment Methodology	A-1
B	Alpha Olefin Specifications	B-1
C	PERP Program Title Index	C-1

Figure	Page
1.1 Schematic View of the Alpha Olefins Business	1
1.2 Overview of Shell's Higher Olefin Process.....	5
1.3 Sasol FT-Derived Alpha Olefin Distribution.....	9
1.4 Trimerization Catalysis.....	10
1.5 Octene-1 Train I Block Flow Diagram	12
1.6 Octene-1 Train II Block Flow Diagram.....	13
1.7 ALPHASELECT [®] Carbon Number Distribution	14
1.8 UOP LINEAR-1 [®] LAO Distribution.....	16
1.9 ALPHA-SABLIN [®] Catalytic Cycle.....	17
1.10 ALPHA -SABLIN [®] Carbon Number Distribution	17
1.11 Simplified Block Diagram of Lummus CPT Process for Hexene-1 Production	19
1.12 Sasol's Proposed Mechanism for Ethylene Tetramerization	20
1.13 Comparison of Commercial Full-Range Alpha Olefin Costs.....	23
1.14 Comparison of Commercial On-Purpose Alpha Olefin Costs.....	24
1.15 Comparison of Developing and Commercial On-Purpose Hexene-1 Costs.....	24
1.16 Comparison of Commercial and Developing On-Purpose Octene-1 Costs.....	25
1.17 Linear Alpha Olefin Demand by Fraction	26
1.18 Linear Alpha Olefin Demand by End-Use.....	27
1.19 Alpha Olefin Growth Rates and Availability.....	28
2.1 Schematic View of the Alpha Olefins Business	30
2.2 Theoretical Alpha Olefin Distribution by Single Stage Ethylene Oligomerization ..	35
2.3 Theoretical Alpha Olefin Distribution by Two-Stage Ethylene Oligomerization	36
2.4 Comparative Theoretical Alpha Olefin Carbon Distributions	37
3.1 Chevron Phillips Full-Range LAO Process	44
3.2 Chevron Phillips Full-Range LAO – Reaction Section	45
3.3 Chevron Phillips Full-Range LAO Distribution	47
3.4 Overview of Shell's Higher Olefin Process.....	48
3.5 Shell Higher Olefin Process (SHOP) Oligomerization Section.....	50
3.6 Shell Higher Olefins Process (SHOP) Alpha Olefins Separation.....	53

3.7 SHOP Process Isomerization and Disproportionation (I/D).....	55
3.8 Speculative SHOP Mass Balance	57
3.9 SHOP LAO/LIO Distribution	57
3.10 INEOS Alpha Olefin Technology.....	59
3.11 INEOS LAO Distributions.....	61
3.12 Idemitsu Process Schematic View	63
3.13 Idemitsu Process Separation Train Type I	64
3.14 Idemitsu Process Split Separation Train Option.....	65
4.1 Schematic View of C ₄ Streams	66
4.2 Nippon Zeon Extractive Distillation.....	69
4.3 Butene-1 Via Ethylene Dimerization (Axens Alphabutol Process).....	71
4.4 Schematic of Sasol's Secunda Complex.....	73
4.5 Sasol FT-Derived Alpha Olefin Distribution.....	74
4.6 Sasol Hexene-1 from Synthol: Block Flow Diagram	75
4.7 A-Olefin Recovery from F-T Liquids (Sasol) Treatment Plus Iso-Olefin Removal	77
4.8 A-Olefin Recovery From F-T Liquids (Sasol) Superfractionation + Extractive Distillation).....	78
4.9 Trimerization Catalysis.....	79
4.10 Phillips' Hexene-1 Process: Trimerization and Separation	81
4.11 Octene-1 Train 1 Block Flow Diagram	84
4.12 Octene-1 Train II Block Flow Diagram.....	86
4.13 Sasol/Linde Azeotropic Distillation Process	87
5.1 ALPHASELECT [®] Carbon Number Distribution	89
5.2 Axens ALPHASELECT [®] Process Flow Diagram.....	91
5.3 UOP LINEAR-1 [®] LAO Distribution	93
5.4 Linear-1 Process [®] Flow Diagram	94
5.5 ALPHA-SABLIN [®] Catalytic Cycle.....	97
5.6 ALPHA -SABLIN [®] Carbon Number Distribution	98
5.7 ALPHA-SABLIN [®] Schematic View	99
6.1 Hexene Isomers Thermodynamic Equilibrium.....	102
6.2 Simplified Block Diagram of Lummus CPT Process for Hexene-1 Production	103
6.3 Dow Butadiene Telomerization Octene-1 Process	108

6.4	Sasol's Proposed Mechanism for Ethylene Tetramerization	111
6.5	Octene-1 via Ethylene Tetramerization	113
6.6	Sasol Octene-1 from Mixed C ₇ Stream.....	115
7.1	Comparison of Commercial Full-Range Alpha Olefin Costs	128
7.2	Comparison of Commercial On-Purpose Alpha Olefin Costs	136
7.3	Comparison of Developing and Commercial On-Purpose Hexene-1 Costs.....	143
7.4	Comparison of Commercial and Developing On-Purpose Octene-1 Costs.....	144
8.1	Alpha Olefin Market Segments	146
8.2	Selected Plasticizer Properties	151
8.3	Linear Alpha Olefin Demand by Fraction	154
8.4	Linear Alpha Olefin Demand by End-Use.....	155
8.5	Alpha Olefin Growth Rates and Availability.....	156
8.6	North American Alpha Olefin Demand by Carbon Number	158
8.7	North American Alpha Olefin Demand by Application Segment	159
8.8	West European Alpha Olefin Demand by Carbon Number, End 2006	161
8.9	West European Alpha Olefin Demand by Application Segment, End 2006	162
8.10	Japanese Alpha Olefin Demand by Carbon Number, End 2006	163
8.11	Japanese Alpha Olefin Demand by End-Use, End 2006	164
8.12	East Asian Alpha Olefin Demand by Comonomer.....	165
8.13	East Asian Alpha Olefin Demand by Application.....	166
8.14	Alpha Olefin Consumption by Country.....	167

Table	Page
1.1 Sasol FT-Derived Mixed Hexene/Hexane Stream Composition	9
1.2 Summary of Commercial Full-Range Alpha Olefin Process Economics	22
1.3 Summary of Commercial On-Purpose Alpha Olefin Process Economics	23
2.1 Theoretical Alpha Olefin Distribution by Single Stage Ethylene Oligomerization ..	35
2.2 Theoretical Alpha Olefin Distribution by Two-Stage Ethylene Oligomerization	36
2.3 Highlights of Selected Alpha Olefins Patents.....	39
4.1 C ₄ Stream Composition.....	67

4.2	C ₄ Component Solubility in DMF	68
4.3	Sasol FT-Derived Mixed Hexene/Hexane Stream Composition	74
6.1	Product Distribution of the Octene-1 from Butadiene Process.....	106
6.2	Typical Analysis of a Crude C ₄ Stream from a Naphtha Cracker	107
6.3	Assumed Sasol Feedstock Composition (After Removal of Oxygenates)	116
6.4	Boiling Points of Various Octanol Isomers	118
6.5	Boiling Points of Components in Dehydration Reactor Effluent	119
7.1	Unit Prices of Economic Inputs	120
7.2	Cost of Production Estimate for: Full-Range Alpha Olefins Process: Chevron Phillips	123
7.3	Cost of Production Estimate for: Full-Range Alpha Olefins Process: INEOS	124
7.4	Cost of Production Estimate for: Full-Range Alpha Olefins Process: Shell (SHOP)	126
7.5	Cost of Production Estimate for: Full-Range Alpha Olefins Process: Idemitsu	127
7.6	Summary of Commercial Full-Range Alpha Olefin Process Economics	128
7.7	Cost of Production Estimate for: On-Purpose Hexene-1 Process: Chevron Phillips Ethylene Trimerization	130
7.8	Cost of Production Estimate for: On-Purpose Hexene-1 Process: Sasol Extraction from Synfuels	131
7.9	Cost of Production Estimate for: On-Purpose Octene-1 Process: Sasol Extraction from Synfuels	132
7.10	Cost of Production Estimate for: On-Purpose Butene-1 Process: Extractive Distillation.....	133
7.11	Cost of Production Estimate for: On-Purpose Butene-1 Process: Alphabutol (Axens)	134
7.12	Summary of Commercial On-Purpose Alpha Olefin Process Economics.....	135
7.13	Cost of Production Summary for: On-Purpose Hexene-1 Process: Lummus CPT® Process	138
7.14	Cost of Production Estimate for: On-Purpose Octene-1 Process: Dow Mixed C ₄ -Based.....	139
7.15	Cost of Production Estimate for: Polyolefin Comonomers (Octene-1, Hexene-1) Process: Sasol Ethylene Tetramerization.....	141

7.16	Cost of Production Estimate for: On-Purpose Octene-1 Process: Sasol C7s from Synfuels via Octanol	142
8.1	Typical Comonomer Incorporation in Polyethylene.....	147
8.2	North American Alpha Olefin Capacity, End 2007	160
8.3	West European Alpha Olefin Capacity, End 2007	163
8.4	Japanese Alpha Olefin Capacity, 2007	164