

*Biodesulfurization of Petroleum
Fractions
98/99S7*

February 2000

TABLE OF CONTENTS

	Page
I EXECUTIVE SUMMARY	1
A. INTRODUCTION	1
B. ECONOMIC CASE STUDY	3
II INTRODUCTION	5
A. BIOTECHNOLOGY PERSPECTIVE	5
1. Background	5
(a) Bioprocessing with Enzymes	5
(b) Genetic Engineering	6
(c) Industrial and Business Development Strategies	6
(d) Extremophiles	7
(e) Challenges of Bioprocessing	7
2. Areas of Application	8
(a) Human and Animal Health and Nutrition	8
(1) Traditional Bioprocessing Applications	8
(2) Bioprotein	9
(3) Health Care	10
(b) Agricultural Inputs and Outputs	11
(1) Genetic Engineering Goals	11
(2) Progress and Threats	11
(3) Investment Recovery	12
(4) Advanced Developments	12
(c) Commodity, Specialty Chemicals, and Fuels	13
(1) Commodity Chemicals	13
(2) Specialty and Fine Chemicals	14
(3) Fuels	14
(d) Minerals Extraction and Processing	15
(e) Waste Treating and Site and Ecosystem Remediation	15
(f) Industrial Enzymes	16
(g) Other Advanced Applications	16
3. Development Challenges for Biotechnology in Commodity Applications	17
(a) Overview	17
(b) Cultural Disconnects	17
(c) Engineering Development	18
(d) Gene Mapping	18

**TABLE OF CONTENTS
(Continued)**

	Page
B. BIOTECH IN PETROLEUM APPLICATIONS	18
1. Crude Upgrading	18
(a) Downhole	19
(b) Oilfield	19
2. Refinery	19
(a) Crude	19
(b) Gasoline	20
(c) Distillate	20
(d) Environmental	20
3. Petrochemicals	21
C. REFINING PERSPECTIVE	21
1. Industry Structure	21
2. Products and Trends	21
3. Summary of Company Interests and Positions in Biotech	22
4. Refinery Hydrodesulfurization Configurations	23
D. DISTILLATE DESULFURIZATION MARKET DRIVERS	23
1. Crude Oil Quality Trends	23
2. Impact on Distillate Quality	24
3. Distillate Specifications	25
(a) Sulfur and Aromatics	26
(b) Cetane Number and Cetane Index	27
(c) Density and Distillation	28
(d) Regulatory Issues	28
(e) Distillate Pool Impact	30
E. CONVENTIONAL HDS TECHNOLOGY	33
1. Introduction	33
2. Hydrodesulfurization Catalysts	34
3. Process Overview and Chemistry	34
4. Technology Licensors	35
(a) Introduction	35
(b) UOP	36
(c) ABB Lummus/Criterion Catalyst Company	37
(d) Others	38

TABLE OF CONTENTS (Continued)

	Page
F. ENERGY BIOSYSTEMS CORPORATION (EBC) DIESEL BIODESULFURIZATION	38
1. Background and History	38
2. BDS Terminology and Pathway	39
3. BDS Technology Overview	41
III DISTILLATE DESULFURIZATION TECHNOLOGY	42
A. DISTILLATE HYDRODESULFURIZATION	42
1. Introduction	42
(a) Background	42
(b) Terminology	43
2. Conventional Desulfurization	45
(a) Overview	45
(b) Hydrodesulfurization Catalysts	46
(1) Composition	46
(2) Use	47
(c) Process Description	48
(1) Introduction	48
(2) Process Overview and Chemistry	50
3. Performance Data	52
4. New Developments	53
(a) Introduction	53
(b) Catalyst Development	54
(1) Non-Noble Metal Hydrotreating Catalysts	54
(2) Noble Metal Catalysts	55
(c) Deep Desulfurization	56
(d) Desulfurization with Dearomatization	60
(1) Introduction	60
(2) Two Stage Hydrotreating	63
(3) SynSat	68
B. EBC DIESEL BIODESULFURIZATION PROCESS	74
1. Introduction	74
2. Process Chemistry	75
3. Process Description	77

**TABLE OF CONTENTS
(Continued)**

	Page
4. Major Technology Hurdles	79
(a) Conversion/Activity	79
(b) Selectivity/Yield	80
(c) Longevity/Catalyst Life	80
5. Outlook for Commercialization	80
IV ECONOMIC ANALYSIS	82
A. INTRODUCTION	82
1. Basis for Economic Analysis	82
(a) Capital Investment Basis	82
(b) Production Cost Basis	82
(c) Raw Material, Byproduct, and Utility Pricing Basis	84
2. Case Study Definition	85
(a) Introduction	85
(b) BDS Configuration Basis	85
(c) BDS/HDS Case Study	86
B. BIODESULFURIZATION PROCESS ECONOMICS	88
1. Capital Cost	88
(a) Base Case	88
(b) Sensitivity Cases	88
2. Cost of Production	88
(a) Base Case	88
(b) Sensitivity Cases	89
(c) Other BDS Applications	91
(d) BDS By-product Potential	92
C. HYDRODESULFURIZATION PROCESS ECONOMICS	93
1. Capital Costs	93
2. Costs of Production	93
(a) Base Case	93
(b) Sensitivity Cases	96
D. CONCLUSIONS	96
GENERAL REFERENCES	98
APPENDIX	100
PERP TITLE INDEX	105

TABLES

	Page	
Table I.B.1	Deep Desulfurization Cost per Barrel of Distillate	4
Table II.D.1	Diesel Specifications in Europe and the United States	29
Table II.D.2	Global Transportation Diesel Demand Profile	31
Table II.D.3	Distillate Blending Components	31
Table II.D.4	Typical Distillate Product Blends Components	33
Table II.F.1	Desulfurization Effectiveness of Rhodococcus IGTS8 on Different Sulfur-Bearing Petroleum Compounds Relative to Dibenzothiophene	40
Table III.A.1	Typical Performance Data of Conventional Distillate Desulfurization	53
Table III.A.2	Low Aromatics/Low Diesel Specifications	61
Table III.A.3	Typical Performance Data for Single Stage High Severity Hydrodesulfurization	63
Table III.A.4	Typical Performance Data of Two Stage Hydrotreating for Desulfurization and Dearomatization	67
Table III.A.5	Typical Product Yield/Properties of the SynSat Process	73
Table IV.A.1	Production Cost Assumptions	83
Table IV.A.2	Feed, Product and Utility Pricing	84
Table IV.B.1	EBC BDS Cost of Production	89
Table IV.B.2	Cost Estimate of Diesel Fuel (50 PPM Sulfur) Process: EBC Biodesulfurization	90
Table IV.B.3	BDS Cost of Production (Ex Feed) vs. Capital Cost	91
Table IV.C.1	SynSat HDS Cost of Production (Ex Feed)	94
Table IV.C.2	Cost Estimate of Diesel Fuel (50 PPM Sulfur) Process: SynSat Hydrodesulfurization (Revamp)	95
Table IV.C.3	SynSat Cost of Production vs. Capital Cost	96
Table IV.D.1	Deep Desulfurization Costs per Barrel of Distillate	97

FIGURES

	Page
Figure II.D.1 U.S. Composite Crude Oil Quality	25
Figure II.E.1 Hydrodesulfurization Reactions	35
Figure III.A.1 Schematic Flow Scheme for Typical Sophisticated Refinery	44
Figure III.A.2 Typical Hydrosulfurization Process	49
Figure III.A.3 Product Sulfur and % HDS Versus Residence Time	58
Figure III.A.4 Typical Two Stage HDS/HDA Process	65
Figure III.A.5 SynSat Process	70
Figure III.A.6 SynSat Catalyst Applications	72
Figure III.B.1 DBT BDS Pathway	76
Figure III.B.2 EBC BDS Process Flow Diagram	78
Figure IV.A.1 Diesel Biodesulfurization - Case Study	87