

TECHNOLOGY & COSTS**Technoeconomics - Energy & Chemicals (TECH)****TECH 2019S5 Maximizing Petrochemical
Production from Refineries**

Table of Contents

A Report by **Nexant, Inc.**

Published Date: December 2019

www.nexantsubscriptions.com**Contents**

1	Executive Summary	1
1.1	Crude Oil to Chemicals (COTC) as a Concept	1
1.2	Key Commercial Process Technologies	3
1.3	COTC Refinery Configuration Economics.....	4
1.3.1	COTC Configurations versus “Conventional” Integrated Refinery/Petrochemical Configurations	4
1.3.2	Return on Capital Employed (ROCE) Analysis	4
1.4	Supply Impact of COTC Capacity Additions	5
2	Introduction.....	8
2.1	Crude Oil to Chemicals (COTC) as a Concept	8
3	Key Commercial Process Technologies	12
3.1	VGO/AGO/Diesel Hydrocracking	12
3.1.1	Chevron Lummus Global ISOCRACKING Process	12
3.1.2	UOP Unicracking™ Process	16
3.1.3	Axens HyK™ Process	23
3.2	Residue Hydrocracking	30
3.2.1	Chevron Lummus Global LC-FINING/LC-MAX® Processes	30
3.2.2	Chevron Lummus Global LC-SLURRY® Process	38
3.2.3	Axens H-Oil® Process	41
3.2.4	UOP Uniflex™ Process	53
3.2.5	KBR Veba Combi Cracking Technology (VCC™)	62
3.3	Delayed Coking and Flexicoking.....	71
3.3.1	Chevron Lummus Global (CLG) Delayed Coking Process	72
3.3.2	Wood (Foster Wheeler) SYDECSM Delayed Coking Process	79
3.3.3	Flexicoking™	85
3.4	Solvent Deasphalting	92
3.4.1	Introduction.....	92
3.4.2	KBR ROSE® Technology	93
3.5	Residue Gasification	99

3.5.1	Introduction.....	99
3.5.2	Shell/Air Products Residue Gasification Technology.....	100
3.6	Fluidized Catalytic Cracking and its Variants (FCC/RFCC/HS-FCC)	106
4	Emerging Process Technologies	108
4.1	Introduction.....	108
4.2	Saudi Aramco Thermal Crude to Chemicals.....	108
4.3	Saudi Aramco High Severity Catalytic Cracking of Crude Oil.....	110
4.4	Reliance MCC Process	110
5	COTC Refinery Configuration Economics.....	112
5.1	Introduction.....	112
5.2	COTC Configurations versus “Conventional” Integrated Refinery/Petrochemical Configurations	112
5.2.1	“Conventional” Refinery Configuration – Case 1	112
5.2.2	“Conventional” Refinery Configuration – Case 2	115
5.2.3	COTC Refinery Configuration – Case 3.....	118
5.2.4	COTC Refinery Configuration – Case 4.....	121
5.2.5	Summary	124
5.3	Return on Capital Employed (ROCE) Analysis	124
5.3.1	Economic Analysis Assumptions and Basis	124
5.3.2	Economic Analysis Results	127
5.3.3	Summary	137
6	Case Studies	139
6.1	High Level of Traditional Refinery-Petrochemical Integration.....	139
6.1.1	ExxonMobil Singapore	139
6.1.2	Fujian Refining and Petrochemical (FREP)	145
6.1.3	Refinery and Petrochemical Integrated Development (RAPID) Project.....	149
6.2	Crude Oil to Chemicals (COTC).....	153
6.2.1	Hengli	154
6.2.2	Zhejiang.....	158
6.2.3	SABIC/Saudi Aramco Yanbu COTC	162
7	Supply Impact of COTC Capacity Additions	164
7.1	Overview.....	164
7.2	Impact on Global Refined Products Markets.....	164
7.3	Impact on Global Ethylene and para-Xylene Markets.....	166

Appendices

A	Definitions of Capital Cost Terms Used in Process Economics.....	172
B	Definitions of Operating Cost Terms Used in Process Economics	177
C	TECH Program Title Index (2009-2019)	180
D	References	183

Figures

Figure 1	Evolution of the Refining and Petrochemical Industry	1
Figure 2	Global Demand v/s Indicative Yields for Traditional and Petrochemical-Integrated Refineries v/s COTC Processes	2
Figure 3	Comparison of Yields for Different Refinery Configurations	4
Figure 4	ROCE Analysis for Different Cases	5
Figure 5	World-Scale Capacity versus Annual Incremental Petrochemicals Demand	6
Figure 6	Global <i>para</i> -Xylene Plants by Capacity	6
Figure 7	Global Ethylene Plants by Capacity	7
Figure 8	Evolution of the Refining and Petrochemical Industry	8
Figure 9	Global Demand v/s Indicative Yields for Traditional and Petrochemical-Integrated Refineries v/s COTC Processes	9
Figure 10	World-Scale Capacity versus Annual Incremental Petrochemicals Demand	10
Figure 11	Two Stage with Recycle (TSREC) Isocracking Configuration	14
Figure 12	UNICRACKING Reaction Section	18
Figure 13	UNICRACKING Fractionation Section	19
Figure 14	UOP's Hydroprocessing Experience ⁽²⁾	23
Figure 15	Overview of Axens HyK™ Process Scheme	25
Figure 16	CLG LC-FINING Simplified Process Flow Diagram	33
Figure 17	Schematic of an LC-FINING Reactor	34
Figure 18	LC-MAX Block Flow Diagram	35
Figure 19	CLG LC-SLURRY Simplified Process Flow Scheme	39
Figure 20	H-Oil Overall Block Flow Diagram	44
Figure 21	H-Oil Reaction and Fractionation Sections	45
Figure 22	H-Oil Ebullated-bed Reactor	47
Figure 23	UOP Uniflex™ Simplified Process Flow Scheme	55
Figure 24	Simplified VCC Process Flow Scheme	65
Figure 25	CLG Delayed Coking Process Flow Diagram	75
Figure 26	Delayed Coker Process Diagram	80
Figure 27	Vapor Recovery Unit	81
Figure 28	Similarities between Fluidized Catalytic Cracking and Flexicoking	86
Figure 29	FLEXICOKING™ Process Flow Diagram	88
Figure 30	ROSE® Process Flow Diagram	94
Figure 31	SGP: Gasification and Syngas Cooling	102
Figure 32	SGP: Soot Separation and Filtration (SARU) Process Flow Diagram	103
Figure 33	Saudi Aramco TC2C COTC Technology Block Flow Diagram	108
Figure 34	Case 1 Product Slate	113
Figure 35	Case 1	114
Figure 36	Case 2 Product Slate	116
Figure 37	Case 2	117
Figure 38	Case 3 Product Slate	119
Figure 39	Case 3	120

Figure 40	Case 4 Product Slate.....	122
Figure 41	Case 4	123
Figure 42	Comparison of Yields for Different Refinery Configurations.....	124
Figure 43	ROCE Analysis for Different Cases.....	137
Figure 44	Historical ROCE for Different Cases, Middle East	138
Figure 45	Historical ROCE for Different Cases, China.....	138
Figure 46	Singapore Integrated	144
Figure 47	Fujian Refining and Petrochemical Complex Block Flow Diagram	148
Figure 48	RAPID Project Block Flow Diagram	152
Figure 49	Hengli COTC Plant Assumed Configuration	157
Figure 50	Zhejiang Petrochemical Complex Configuration	161
Figure 51	Global Refined Products Demand.....	164
Figure 52	Refined Products Demand Growth versus Refined Products Capacity Additions	166
Figure 53	World-Scale Capacity versus Annual Incremental Petrochemicals Demand.....	167
Figure 54	Global <i>para</i> -Xylene Plants by Capacity	168
Figure 55	Global <i>para</i> -Xylene Supply and Demand	168
Figure 56	Global Ethylene Plants by Capacity	169
Figure 57	Global Ethylene Supply and Demand	170

Tables

Table 1	Refining Technology Holders and Licensors	3
Table 2	Feeds for Hydrocrackers	12
Table 3	Typical Yields and Product Qualities from Isocracking	15
Table 4	Utility Consumption	15
Table 5	Unicracking Unit Feedstock	21
Table 6	Unicracking Unit Product Yields	21
Table 7	Unicracking Unit Product Qualities	22
Table 8	Unicracking Unit Utility Requirements	22
Table 9	HyK Unit Feedstock Properties	27
Table 10	HyK Unit Product Yields	27
Table 11	HyK Unit Product Qualities	28
Table 12	HyK Utility Requirements	28
Table 13	HyK References	29
Table 14	LC-FINING Product Yields	36
Table 15	LC-FINING Product Qualities	36
Table 16	LC-MAX Product Yields	37
Table 17	LC-MAX Product Qualities	37
Table 18	LC-FINING/LC-MAX Commercial Experience	37
Table 19	LC-SLURRY Product Yields and Qualities	40
Table 20	LC-SLURRY Commercial Experience	41
Table 21	H-Oil Unit Feedstock Properties	48
Table 22	H-Oil Process Performance	49
Table 23	H-Oil Process Yields	49
Table 24	H-Oil Unit Product Properties	50
Table 25	Estimated H-Oil Unit Investment	50
Table 26	H-Oil Unit Utilities Summary	51
Table 27	H-Oil References	52
Table 28	Uniflex Unit Feedstock: Arab Medium Vacuum Residue	58
Table 29	Uniflex Unit Product Yields	58
Table 30	Uniflex Unit Product Properties	59
Table 31	Estimated Uniflex Investment for Configuration with Integrated DHT	60
Table 32	Uniflex Utility Requirements	60
Table 33	List of UOP Uniflex Licenses	61
Table 34	VCC Unit Feedstock	67
Table 35	Typical VCC Unit Product Yields	68
Table 36	Typical VCC Unit Product Properties – Maximum Naptha Case	68
Table 37	VCC Unit Utilities Summary	69
Table 38	Licensed Units in Operation since Commercialization	70
Table 39	Licensee List	70
Table 40	CLG Delayed Coking Process Product Yields	76
Table 41	CLG Delayed Coking Process Product Qualities	77
Table 42	CLG Delayed Coking Commercial Experience List	78
Table 43	Feedstock Characteristics for Various Vacuum Residues	83
Table 44	Typical Yield and Product Properties for Various Delayed Coker Feedstocks	84

Table 45	Utility Requirements for SYDEC SM Delayed Coker	85
Table 46	Typical Flexicoking Unit Yields and Product Properties	90
Table 47	Flexicoking Unit Utility Requirements	90
Table 48	Flexicoking Commercial Units	91
Table 49	Maximum ROSE Unit DAO Yields by Solvent Type	96
Table 50	SDA Unit DAO Qualities	96
Table 51	Utility Requirements for ROSE Process	98
Table 52	Gasifier Feedstock: SDA Pitch	104
Table 53	Raw Syngas Characteristics	104
Table 54	Examples of Shell Gasification Process Refinery and Heavy Oil Applications	105
Table 55	Yields for Conventional and High Severity FCC	106
Table 56	Enhanced FCC Technology Licensors	107
Table 57	Saudi Aramco TC2C Technology Product Slate	109
Table 58	Saudi Aramco High Severity FCC COTC Product Slate	110
Table 59	Reliance MCC COTC Product Yields	111
Table 60	Case 1 Processing Units and Capacities	113
Table 61	Case 2 Processing Units and Capacities	115
Table 62	Case 3 Processing Units and Capacities	118
Table 63	Case 4 Processing Units and Capacities	121
Table 64	Pricing Basis	126
Table 65	Cost of Production Estimate for Conventional Refinery Case 1	128
Table 66	Cost of Production Estimate for Conventional Refinery Case 2	129
Table 67	Cost of Production Estimate for COTC Refinery Case 3	130
Table 68	Cost of Production Estimate for COTC Refinery Case 4	131
Table 69	Cost of Production Estimate for Conventional Refinery Case 1	133
Table 70	Cost of Production Estimate for Conventional Refinery Case 2	134
Table 71	Cost of Production Estimate for COTC Refinery Case 3	135
Table 72	Cost of Production Estimate for COTC Refinery Case 4	136
Table 73	Exxon Mobil Singapore Petrochemical Products	140
Table 74	ExxonMobil Singapore Refinery Process Units	141
Table 75	Exxon Mobil Singapore Complex Petrochemicals Products	141
Table 76	FREP Main Petrochemical Products	145
Table 77	FREP Refinery Major Process Units	146
Table 78	Main RAPID Project Petrochemical Products	150
Table 79	RAPID Refinery Major Process Units	150
Table 80	Main Hengli Complex Petrochemical Products	154
Table 81	Hengli Refinery Major Process Unit Capacities	155
Table 82	Hengli Complex Petrochemical Plant Capacities	156
Table 83	Main Zhejiang Complex Petrochemical Products	159
Table 84	ZPC Refinery Major Process Unit Capacities	159
Table 85	ZPC Complex Petrochemical Plant Capacities	160

Nexant Inc.

TECHNOLOGY & COSTS

Technoeconomics - Energy & Chemicals (TECH)

The Nexant Subscriptions' Technoeconomics - Energy & Chemicals (TECH) program is recognized globally as the industry standard source for information relevant to the chemical process and refining industries. Technoeconomics - Energy & Chemicals (TECH) reports are available as a subscription program or on a single report basis.

Contact Details:

Americas:

Marcos Nogueira Cesar, Vice President, Global Products, E&CA: Nexant Subscriptions

Phone: + 1-914-609-0324, e-mail: mcesar@nexant.com

Erica Hill, Client Services Coordinator, E&CA-Products

Phone: + 1-914-609-0386, e-mail: ehill@nexant.com

EMEA:

Anna Ibbotson, Director, Nexant Subscriptions

Phone: +44-207-950-1528, aibbotson@nexant.com

Asia:

Chommanad Thammanayakatip, Managing Consultant, Energy & Chemicals Advisory

Phone: +66-2793-4606, email: chommanadt@nexant.com

Nexant, Inc. (www.nexant.com) is a leading management consultancy to the global energy, chemical, and related industries. For over 38 years, Nexant has helped clients increase business value through assistance in all aspects of business strategy, including business intelligence, project feasibility and implementation, operational improvement, portfolio planning, and growth through M&A activities. Nexant has its main offices in San Francisco (California), White Plains (New York), and London (UK), and satellite offices worldwide.

Copyright © by Nexant Inc. 2018. All Rights Reserved.