
WORLDWIDE REFINERY PROCESSING REVIEW

Monitoring Technology Development and Competition in One Single Source

Third Quarter 2019

Hydrotreating, and Refinery-Petrochemical Integration & Crude-to-Chemicals

Plus

Latest Refining Technology Developments & Licensing



HYDROCARBON PUBLISHING COMPANY

Translating Knowledge into Profitability®

P.O. Box 815, Paoli, PA 19301-0815 (U.S.A.)

Phone: (610) 408-0117

Review@Hydrocarbonpublishing.com

WORLDWIDE REFINERY PROCESSING REVIEW

Monitoring Technology Development and Competition in a Single Source

Third Quarter 2019

Hydrotreating, and Refinery-Petrochemical Integration & Crude-to-Chemicals

Plus

Latest Refining Technology Developments & Licensing

<http://www.hydrocarbonpublishing.com>

WORLDWIDE REFINERY PROCESSING REVIEW is published by Hydrocarbon Publishing Co. every quarter. Copyright 2007-2019. All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or translated into any language or by any means—electronic, mechanical, photocopying, recording or otherwise—without prior written permission of Hydrocarbon Publishing Company. P.O. Box 815, Paoli, PA 19301-0815 (USA). Tel: (610) 408-0117. E-mail: review@hydrocarbonpublishing.com

3Q 2019 Review

Hydrotreating, and Refinery-Petrochemical Integration & Crude-to-Chemicals

1. INTRODUCTION.....	1
2. HYDROTREATING	5
2.1 <i>Market/Technology Trends & Opportunities</i>	<i>5</i>
2.1.1 Introduction.....	5
2.1.2 Market Conditions and Outlook	5
2.1.2.1 Global Transportation Fuels Specifications.....	5
2.1.2.1.1 Motor Gasoline.....	7
2.1.2.1.2 Middle Distillates.....	9
2.1.2.1.3 Bunker Fuel	12
2.1.2.1.4 Renewable and Bio-fuel Mandates	12
2.1.2.2 Global Refined Products Demand.....	17
2.1.2.2.1 Gasoline.....	18
2.1.2.2.2 Diesel/Gasoil	19
2.1.2.2.2.1 Diesel Losing Ground to Alternatives in Parts of the World.....	19
2.1.2.2.2.2 Short-term Diesel Growth Opportunities.....	21
2.1.2.2.2.3 IMO 2020 Mandate Bolsters Diesel Demand	22
2.1.2.2.3 Jet Fuel	23
2.1.2.2.4 Renewable- and Bio-based Fuels	24
2.1.2.2.4.1 Renewable and Bio-based Diesel	24
2.1.2.2.4.2 Renewable and Bio-based Jet Fuel.....	28
2.1.2.3 Shifting Crude Slate.....	31
2.1.2.3.1 Opportunity Crudes.....	31
2.1.2.3.2 Shale/Tight Oil.....	35
2.1.2.4 Hydrogen Demand.....	36
2.1.2.5 Capacity Expansion	37
2.1.2.6 Construction Projects and Unit Revamps	38
2.1.2.7 Hydrotreating Catalysts Market.....	39
2.1.3 Technology Competition, Latest Trends, Research Developments, and Future Prospects	40
2.1.3.1 Conventional Hydrotreating	42
2.1.3.1.1 Diesel Hydrotreating	43
2.1.3.1.1.1 Hydrocracker Pretreatment	43
2.1.3.1.1.2 ULSD Production	45
2.1.3.1.1.3 Volume Swell.....	46
2.1.3.1.1.4 Dewaxing.....	47
2.1.3.1.1.5 LCO Upgrading.....	47
2.1.3.1.2 Gasoline Hydrotreating	48
2.1.3.1.2.1 FCC Pretreatment.....	49
2.1.3.1.2.2 FCC Posttreatment	51
2.1.3.1.3 Summary of Major Technology Offerings	52
2.1.3.1.4 Reactor Internals	54
2.1.3.1.5 H ₂ Consumption.....	55
2.1.3.1.6 Advanced Process Control.....	56
2.1.3.1.7 Process Integration.....	57
2.1.3.2 Heavy Oil/Resid Hydrotreating	57
2.1.3.3 Renewable Feed Hydrotreating	60
2.1.3.4 Latest R&D Trends	61

2.1.4	Conclusion	62
2.2	<i>State-of-the-Art Technology</i>	63
2.2.1	Introduction	63
2.2.2	Commercial Catalysts and Guard Materials	64
2.2.2.1	Advanced Refining Technologies.....	65
2.2.2.1.1	SmART.....	66
2.2.2.1.2	ApART	73
2.2.2.1.3	StART.....	76
2.2.2.2	Albemarle.....	77
2.2.2.2.1	XPLORE Series	78
2.2.2.2.2	STARS Series.....	81
2.2.2.2.3	NEBULA Series	91
2.2.2.2.4	Combined Implementation.....	97
2.2.2.2.5	KF 901, KF 902, KF 905, KF 859	99
2.2.2.2.6	KF 200	100
2.2.2.2.7	Guard Catalysts.....	100
2.2.2.3	Axens.....	102
2.2.2.3.1	Impulse	102
2.2.2.3.2	HR 400 Series.....	104
2.2.2.3.3	HR 500 Series.....	105
2.2.2.3.4	HR 600 Series.....	107
2.2.2.3.5	HR 900 Series.....	108
2.2.2.3.6	AX 740 Hydrogenation Catalysts.....	109
2.2.2.3.7	ACT Grading Materials	109
2.2.2.4	BASF.....	110
2.2.2.5	Chevron Lummus Global	110
2.2.2.6	Clariant	113
2.2.2.7	Cosmo Oil	115
2.2.2.8	Crystaphase Products.....	115
2.2.2.9	ExxonMobil.....	118
2.2.2.9.1	RT-225.....	119
2.2.2.9.2	RT-235.....	119
2.2.2.9.3	OCTGAIN Catalysts.....	120
2.2.2.10	Haldor Topsoe	121
2.2.2.10.1	Coker Naphtha Hydrotreating	123
2.2.2.10.2	FCC Gasoline Posttreat	125
2.2.2.10.3	Naphtha and Kerosene Production	125
2.2.2.10.4	ULSD Production	126
2.2.2.10.5	Reduction of Diesel Density and Aromatics.....	131
2.2.2.10.6	Diesel Dewaxing.....	132
2.2.2.10.7	FCC Feed Pretreat	135
2.2.2.10.8	Hydrocracker Pretreating	136
2.2.2.10.9	Graded Bed Products for Pressure Drop Control.....	138
2.2.2.11	Honeywell UOP	142
2.2.2.12	JGC Catalysts & Chemicals Industries.....	150
2.2.2.13	Johnson Matthey Catalysts	151
2.2.2.14	Nippon Oil	151
2.2.2.15	Porocel	152
2.2.2.16	Shell Catalysts & Technologies	152
2.2.2.16.1	CENTINEL	157
2.2.2.16.2	CENTINEL GOLD	159

2.2.2.16.3	ASCENT	161
2.2.2.16.4	CENTERA.....	169
2.2.2.16.5	SDD-800/SDD-821	181
2.2.2.16.6	Selective Hydrogenation Catalysts	185
2.2.2.16.7	Guard Catalysts	185
2.2.2.17	Sinopec Catalyst Co.....	188
2.2.2.18	Saint Gobain NorPro	190
2.2.2.19	TRICAT.....	191
2.2.2.20	Summary of Commercially Available Hydrotreating Catalysts	191
2.2.3	Auxiliary Catalyst Technology	196
2.2.3.1	Advanced Refining Technologies	196
2.2.3.2	Albemarle.....	197
2.2.3.2.1	EasyActive	197
2.2.3.2.2	REACT	197
2.2.3.2.3	STAX.....	198
2.2.3.3	Axens.....	204
2.2.3.3.1	Catapac.....	204
2.2.3.3.2	Orchestra.....	205
2.2.3.4	Eurecat	206
2.2.3.5	Haldor Topsoe.....	210
2.2.3.6	HPA	211
2.2.3.7	hte.....	211
2.2.3.8	Orient Catalyst/Advanced Refining Technologies.....	213
2.2.3.9	Porocel	214
2.2.3.9.1	actiCAT Shield	214
2.2.3.9.2	Excel	214
2.2.3.9.3	UltraCAT	216
2.2.3.10	Reactor Resources	216
2.2.3.11	Shell Catalysts & Technologies.....	217
2.2.3.12	TRICAT Inc.	219
2.2.3.12.1	TRICAT Regeneration Process	219
2.2.3.12.2	XpresS.....	219
2.2.4	Commercial Process Technology	220
2.2.4.1	Albemarle.....	220
2.2.4.1.1	UD-HDS.....	220
2.2.4.1.2	HDAr	221
2.2.4.1.3	Cold Flow Improvement	223
2.2.4.1.4	PLEX Reactor Internals	224
2.2.4.2	Axens.....	224
2.2.4.2.1	Prime-G+	225
2.2.4.2.2	Prime-D.....	229
2.2.4.2.3	Benzene Saturation	231
2.2.4.2.4	Coker Naphtha Hydrotreating.....	232
2.2.4.2.5	EquiFlow Reactor Internals	232
2.2.4.3	Chevron Lummus Global.....	235
2.2.4.3.1	ISOTREATING	235
2.2.4.3.2	Reactor Internals	237
2.2.4.4	DuPont Clean Technologies	238
2.2.4.5	ExxonMobil Research & Engineering	243
2.2.4.5.1	GO-Fining.....	243
2.2.4.5.2	HYDROFINING.....	244

2.2.4.5.3	SCANfining	245
2.2.4.5.4	EXOMER	247
2.2.4.5.5	OCTGAIN	248
2.2.4.5.6	MIDW.....	249
2.2.4.6	Fushun Research Institute of Petroleum and Petrochemicals (Sinopec)	254
2.2.4.6.1	FHI Diesel Hydro-upgrading/Isodewaxing Process	254
2.2.4.6.2	FRS	255
2.2.4.6.3	OTA	255
2.2.4.6.4	OCT-M.....	256
2.2.4.7	GTC Technology.....	256
2.2.4.8	Haldor Topsøe	257
2.2.4.8.1	Conventional Hydrotreating	257
2.2.4.8.2	Coker Naphtha Hydrotreating	260
2.2.4.8.3	Diesel Dewaxing.....	261
2.2.4.8.4	Distillate HDS/HDA.....	261
2.2.4.8.5	Aroshift	262
2.2.4.8.6	Polyshift	264
2.2.4.8.7	Revamping	265
2.2.4.8.8	Reactor Internals	266
2.2.4.9	Honeywell UOP	271
2.2.4.9.1	MQD Unionfining.....	274
2.2.4.9.2	VGO Unionfining	276
2.2.4.9.3	ISAL	277
2.2.4.9.4	SelectFining.....	278
2.2.4.9.5	BenSat.....	280
2.2.4.9.6	Unisar.....	281
2.2.4.9.7	Unicracking/DW.....	282
2.2.4.9.8	Reactor Internals	284
2.2.4.10	Instituto Mexicano del Petróleo.....	286
2.2.4.11	JGC Catalysts & Chemicals.....	287
2.2.4.11.1	JUST Refinery	287
2.2.4.11.2	Gas Oil Ultra Deep Desulfurization	288
2.2.4.11.3	GEFINERY	288
2.2.4.11.4	LCO Upgrading	288
2.2.4.12	McDermott Int. Inc.....	289
2.2.4.12.1	Conventional Hydrotreating	289
2.2.4.12.2	Benzene CDHydro	290
2.2.4.12.3	LCN CDHydro/CDHDS and CDHDS+.....	292
2.2.4.13	MOL.....	296
2.2.4.14	Neste Jacobs.....	297
2.2.4.15	Nippon Oil	298
2.2.4.16	RIPP/Sinopec	299
2.2.4.17	SK Corp.	300
2.2.4.18	Shell Catalysts & Technologies	301
2.2.4.18.1	Hydrotreating Process	302
2.2.4.18.2	SMDH	303
2.2.4.18.3	Pyrolysis Hydrogenation Unit	304
2.2.4.18.4	Reactor Internals	304
2.2.4.19	TechnipFMC/BASF	311
2.2.4.20	Summary of Hydrotreating Process Technologies	313

2.2.5	Commercially Available Advanced Control and Optimization Systems	325
2.2.5.1	Aspen Technology.....	325
2.2.5.2	Axens.....	326
2.2.5.3	KBC Advanced Technologies	328
2.2.5.4	Petrobras	329
2.2.5.5	Repsol	330
2.2.6	Resid Hydrotreating.....	331
2.2.7	Coprocessing of Renewable Feed with Conventional Petroleum Feed	337
2.2.7.1	A*STAR.....	339
2.2.7.2	Advanced Refining Technologies	339
2.2.7.3	Albemarle.....	339
2.2.7.4	Axens.....	341
2.2.7.5	Cepsa.....	343
2.2.7.6	Grace.....	345
2.2.7.7	Haldor Topsoe.....	346
2.2.7.7.1	Green Diesel Coprocessing Unit	348
2.2.7.7.2	Standalone Renewable Diesel Hydrotreater	350
2.2.7.8	Honeywell UOP	351
2.2.7.8.1	EcoFining	351
2.2.7.8.2	Renewable Jet Fuel.....	355
2.2.7.9	Hindustan Petroleum Corp. Ltd.	358
2.2.7.10	Neste	359
2.2.7.11	Petrobras	366
2.2.7.12	Repsol	368
2.2.7.13	Total-Amyris.....	368
2.2.7.14	Summary of Renewable Feed Hydrotreating.....	369
2.3	<i>Plant Operations and Practices</i>	370
2.3.1	General Hydrotreating Operations	370
2.3.1.1	Feed Considerations, Process Configuration, and Hardware	371
2.3.1.1.1	Feedstock Characterization	371
2.3.1.1.2	Pre-hydrotreated Feeds	372
2.3.1.1.3	Upgrading Tight Oil.....	373
2.3.1.1.4	Feed Drum Blanketing Gas	376
2.3.1.1.5	Reactor Configuration	376
2.3.1.1.6	Optimizing Reactor Startups and Shutdowns.....	379
2.3.1.1.7	Minimize Fouling of Reactor Internals	379
2.3.1.1.8	Improving Deflector Design within the Quench Zone of Hydroprocessing Reactors	381
2.3.1.1.9	Twisted Tube Exchanger Bundles for Preheat Service	382
2.3.1.1.10	Thermal Enhancement System to Improve Heat Recovery	382
2.3.1.1.11	Improving Recycle Gas Compressor Operation.....	383
2.3.1.1.12	Welded Supports on Reactor Walls.....	384
2.3.1.2	Catalyst Management.....	385
2.3.1.2.1	Measuring Hydrotreating Catalyst Activity	385
2.3.1.2.2	Protecting HT Catalysts from Contamination.....	386
2.3.1.2.3	Determining and Mitigating HDS Catalyst Deactivation.....	393
2.3.1.2.4	Minimizing HDS Activity Loss from Low Sulfur Feed	394
2.3.1.2.5	<i>In situ</i> Catalyst Sulfiding vs. <i>Ex situ</i> Presulfiding.....	394
2.3.1.2.6	Comparison of Various Sulfiding Agents	398
2.3.1.2.7	Determining HDM Range	401
2.3.1.2.8	Using Regenerated Catalyst	402
2.3.1.2.9	Dry Dump vs. Wet Dump Catalyst Change-out Procedures	403

2.3.1.2.10	Catalyst Removal for Non-free Flowing Catalysts.....	403
2.3.1.2.11	Transportation and Disposal of Contaminant-laden Catalysts	404
2.3.1.2.12	Catalyst Dense Loading.....	404
2.3.1.2.13	Catalyst Short Loading	406
2.3.1.3	Operating Conditions and Hydrogen Consumption	407
2.3.1.3.1	Effect of Process Severity/Variables on Hydrotreater Performance	407
2.3.1.3.2	Control of Maximum Reactor Temperature	409
2.3.1.3.3	Using High-purity Hydrogen and/or Adjusting Hydrogen Partial Pressure.....	410
2.3.1.3.4	Optimizing the Hydrogen-to-Oil Ratio	411
2.3.1.3.5	Carbon Oxide Contamination	412
2.3.1.3.6	Mitigating High Temperature Hydrogen Attack	412
2.3.1.3.7	Accurately Measuring Hydrogen Consumption in Hydrotreaters	413
2.3.1.3.8	Membranes for H ₂ Recovery from Hydrotreaters	415
2.3.1.3.9	Parameters Impacting Hydrogen Purity in Recycle Gas.....	415
2.3.1.4	Operational Monitoring and Upset Detection	416
2.3.1.4.1	Process Analyzer Placement	416
2.3.1.4.2	Temperature Monitoring During Startup and Shutdown	416
2.3.1.4.3	Monitoring Tube Metal Temperature in Furnaces	417
2.3.1.4.4	Reactor Effluent Sampling	418
2.3.1.4.5	Accurate Level Measurements in a High Pressure Separator.....	419
2.3.1.4.6	Maldistribution in Hydrotreaters.....	422
2.3.1.4.7	Reactor Pressure Drop Buildup: Causes and Remedies	424
2.3.1.4.7.1	Pressure Drop Issues Due to Catalyst	424
2.3.1.4.7.2	Pressure Drop Issues Due to Plugging/Fouling	425
2.3.1.4.8	Detecting and Mitigating Leaks in Equipment.....	430
2.3.1.4.9	Fouling in Feed/Effluent Exchangers	432
2.3.1.4.10	Ammonium Chloride Fouling in Effluent Exchangers and H ₂ Gas Compressors	435
2.3.1.4.11	Dynamic Simulation to Calculate Column Relief Loads	437
2.3.1.5	Best Practices and Troubleshooting	438
2.3.1.5.1	Reviewing and Updating Unit Operating Procedures	438
2.3.1.5.2	Criteria for Selecting Remote Manual and/or Auto Depressuring Equipment and Instrumentation.....	439
2.3.1.5.3	Interruption of Operations (Emergency or Planned) and Recommended Actions.....	441
2.3.1.5.4	Minimizing Exposure Risks during Reactor Shutdowns	442
2.3.1.5.5	Preventing Flaring during Unit Startup or Shutdown Procedures	442
2.3.1.5.6	Irregularities in Sulfur Content	443
2.3.2	Distillate Hydrotreating	443
2.3.2.1	Diesel Quality Requirements.....	446
2.3.2.1.1	Cetane.....	446
2.3.2.1.2	ULSD Cold Flow Properties	448
2.3.2.1.3	ULSD Haze Point	449
2.3.2.1.4	Minimizing Diesel Color Degradation	449
2.3.2.1.5	Logistics.....	451
2.3.2.2	Increasing Diesel Output	451
2.3.2.2.1	Maximizing Volume Swell of Distillate Feeds	451
2.3.2.2.2	Increasing Distillates Fed into a Hydrotreater	452
2.3.2.3	Hardware Considerations.....	455
2.3.2.3.1	Adjusting Hydrotreater Internals to Improve Diesel Production.....	455
2.3.2.3.2	Limitations of Single Bed or Undersized ULSD Reactors.....	456
2.3.2.3.3	Determining Sufficient Reserve Quench in ULSD Hydrotreaters.....	456
2.3.2.3.4	Optimum Hydrogen Injection Point.....	456
2.3.2.3.5	Using Advanced-phase Separation Techniques	457

2.3.2.3.6	Fouling on Disposable Feed Filters	457
2.3.2.3.7	Designing and Operating a Diesel Salt Dryer	458
2.3.2.3.8	Diesel Hydrotreater Stripper Revamp	458
2.3.2.3.9	Use of Welded Plate and Shell Exchangers in Diesel Hydrotreaters	460
2.3.2.3.10	Improving Energy Efficiency	460
2.3.2.4	Catalyst Management	461
2.3.2.5	Minimizing Hydrogen Use in Diesel Hydrotreating	465
2.3.2.6	Feed Considerations	468
2.3.2.6.1	Options for Converting FCC LCO to ULSD	468
2.3.2.6.2	Processing Distillate and Naphtha Blends in a Diesel Hydrotreater	470
2.3.2.7	Revamps for ULSD Production	471
2.3.2.7.1	Case Study 1	473
2.3.2.7.2	Case Study 2	474
2.3.2.7.3	Case Study 3	474
2.3.2.7.4	Case Study 4	475
2.3.2.7.5	Case Study 5	476
2.3.2.7.6	Case Study 6	478
2.3.2.7.7	Case Study 7	479
2.3.2.8	Ultra-low Sulfur Kerosene Production	480
2.3.2.9	Off-color Products	482
2.3.2.10	Meeting New IMO Bunker Specification	483
2.3.3	Naphtha Hydrotreating	487
2.3.3.1	Hydrotreating FCC Naphtha	487
2.3.3.2	Processing Coker and Visbreaker Naphtha	489
2.3.3.3	Processing Coker Naphtha for Hydrogen Production	495
2.3.3.4	Measuring Silicon Content in Coker Naphtha	496
2.3.3.5	Impact of Inlet Temperature on Naphtha Hydrotreater Performance	497
2.3.3.6	Minimizing Fouling to Increase Catalyst Run Length	498
2.3.3.7	Minimizing Corrosion from Ammonium Salts	500
2.3.3.8	Separating Stripping and Splitting Applications	503
2.3.3.9	Network of Dividing Wall Columns for Naphtha Hydrotreaters	503
2.3.3.10	FCC Naphtha Posttreater Simulation and Optimization	504
2.3.4	Gas Oil Hydrotreating	507
2.3.4.1	Modifying a FCC Feed Pretreater to Increase Yield of Diesel	508
2.3.4.2	Impact of Feed Hydrotreatment on FCC Product Aromatics Content	510
2.3.4.3	Impact of Tier III Gasoline Standards on FCC Feed Pretreaters	511
2.3.4.4	FCC Feed Pretreatment vs. FCC Gasoline HDS	512
2.3.4.5	Improving the Energy Efficiency of FCC Gasoline HDS	519
2.3.4.6	Reducing the Endpoint in Gas Oil Hydrotreaters	520
2.3.4.7	Hydrotreating Heavy Coker Gas Oil	521
2.3.4.8	Predicting the Yield Pattern When Coprocessing LCGO in a VGO FCCU	524
2.3.4.9	Improved Operation of a VGO Hydrotreater	524
2.3.4.10	Operating a VGO Hydrotreater in Blocked Mode	525
2.4	<i>Refining R&D Alert!</i>	526
2.4.1	Introduction	526
2.4.2	General Hydrotreating	532
2.4.2.1	Process	532
2.4.2.1.1	Patents	532
2.4.2.1.2	Research	534

2.4.2.2	Catalyst.....	535
2.4.2.2.1	Patents.....	535
2.4.2.2.1.1	Carriers.....	535
2.4.2.2.1.2	Catalyst Compositions.....	537
2.4.2.2.1.3	Guard Catalysts.....	540
2.4.2.2.1.4	Catalyst Presulfiding.....	542
2.4.2.2.1.5	Preparation Methods.....	544
2.4.2.2.1.6	Other.....	547
2.4.2.2.2	Research.....	548
2.4.3	Middle Distillate Hydrotreating (Including ULSD Production).....	552
2.4.3.1	Process.....	552
2.4.3.1.1	Patents.....	552
2.4.3.1.2	Research.....	555
2.4.3.2	Catalyst.....	557
2.4.3.2.1	Patents.....	557
2.4.3.2.1.1	Catalyst Compositions.....	557
2.4.3.2.1.2	Preparation and Regeneration Methods.....	559
2.4.3.2.2	Research.....	561
2.4.4	Hydrocracking Pretreatment.....	562
2.4.5	FCC Pretreatment.....	563
2.4.5.1	Patents.....	563
2.4.5.2	Research.....	565
2.4.6	FCC Posttreatment.....	566
2.4.6.1	Process.....	566
2.4.6.2	Catalyst.....	570
2.4.6.2.1	Patents.....	570
2.4.6.2.2	Research.....	572
2.4.7	Naphtha Hydrotreating.....	573
2.4.7.1	Process.....	573
2.4.7.2	Catalyst.....	575
2.4.8	Heavy Oil and Resid Hydrotreating.....	576
2.4.8.1	Process.....	576
2.4.8.1.1	Patents.....	576
2.4.8.1.2	Research.....	580
2.4.8.2	Catalyst.....	581
2.4.8.2.1	Patents.....	581
2.4.8.2.1.1	HDM Catalysts.....	581
2.4.8.2.1.2	HDS and/or HDN Catalysts.....	583
2.4.8.2.1.3	Other.....	585
2.4.8.2.2	Research.....	587
2.4.8.2.2.1	HDS and/or HDN Catalysts.....	587
2.4.8.2.2.2	Catalyst Deactivation.....	588
2.4.9	Hydrotreating for Aromatics and Light Olefins Production.....	590
2.4.9.1	Patents.....	590
2.4.9.2	Research.....	592
2.4.10	Renewable Feed Hydrotreating.....	593
2.4.11	Bio-oil Hydrotreating.....	595
2.4.11.1	Process.....	595
2.4.11.1.1	Patents.....	595
2.4.11.1.2	Research.....	597
2.4.11.2	Catalysts.....	601

2.5	Worldwide Installed Capacity	604
2.6	Construction.....	606
2.6.1	Recent Construction Activity	606
2.6.2	Completed Construction Projects.....	617
2.7	References.....	659
3.	REFINERY-PETROCHEMICAL INTEGRATION & CRUDE-TO-CHEMICALS.....	715
3.1	Market/Technology Trends & Opportunities	715
3.1.1	Introduction	715
3.1.2	Market Conditions and Outlook	716
3.1.2.1	Global Fuels Demand	716
3.1.2.2	Global Petrochemicals Supply and Demand	717
3.1.3	Refinery-Petrochemical Integration	722
3.1.3.1	Regional Analysis	722
3.1.3.2	Expanding Petrochemicals Production	723
3.1.3.2.1	North America	723
3.1.3.2.2	Europe	724
3.1.3.2.3	The Middle East	725
3.1.3.2.4	Asia	726
3.1.3.2.5	Africa.....	730
3.1.3.3	Economic Analyses.....	730
3.1.3.4	Integration Drivers and Decision-Making	732
3.1.4	Crude-to-Chemicals	733
3.1.5	Recent Technology Developments	734
3.1.6	Conclusion.....	736
3.2	State-of-the-Art Technology	738
3.2.1	Introduction	738
3.2.2	Refinery-Petrochemical Integration	740
3.2.2.1	Maximizing Hydrocracker Naphtha	743
3.2.2.1.1	Process	743
3.2.2.1.2	Catalysts	743
3.2.2.2	Increasing FCC Feedstock.....	744
3.2.2.3	Increasing the BTX Content of FCC Naphtha	745
3.2.2.3.1	Honeywell UOP	745
3.2.2.3.2	Sinopec	746
3.2.2.4	Maximizing FCC LCO	748
3.2.2.4.1	Processes.....	749
3.2.2.4.1.1	KBR	749
3.2.2.4.1.2	Petrobras.....	750
3.2.2.4.1.3	Sinopec	750
3.2.2.4.2	Catalysts and Additives	750
3.2.2.4.2.1	Albemarle	751
3.2.2.4.2.2	BASF Catalysts	755
3.2.2.4.2.3	Grace Catalysts Technologies	760
3.2.2.4.2.4	Johnson Matthey.....	765
3.2.2.4.2.5	Sinopec Catalyst Co.	766
3.2.2.5	Converting LCO to Aromatics.....	767
3.2.2.5.1	Honeywell UOP	767
3.2.2.5.2	Sinopec	768

3.2.2.6	Cracking Heavy Olefins to Propylene	771
3.2.2.6.1	Asahi Kasei Chemicals	771
3.2.2.6.2	ExxonMobil	771
3.2.2.6.2.1	Mobil Olefins Interconversion (MOI)	771
3.2.2.6.2.2	Propylene Catalytic Cracking (PCC)	773
3.2.2.6.3	Honeywell UOP/Total Petrochemicals	774
3.2.2.6.4	KBR	775
3.2.2.6.5	Linde/Lurgi	777
3.2.2.6.6	Sinopec	779
3.2.2.7	Oxidative Coupling of Methane	780
3.2.2.8	Propylene Production and Recovery	780
3.2.2.8.1	Petrochemical FCC	780
3.2.2.8.2	On-purpose Propylene Production	785
3.2.2.8.3	Propylene Recovery from Refinery Offgas	789
3.2.2.9	Aromatics Production and Recovery	792
3.2.3	Crude-to-Chemicals	800
3.2.3.1	Direct Crude Cracking	801
3.2.3.1.1	ExxonMobil	801
3.2.3.1.2	Lummus Technology	801
3.2.3.2	Refinery Reconfiguration	802
3.2.3.2.1	Honeywell UOP	802
3.2.3.2.2	Saudi Aramco	804
3.2.3.2.2.1	TC2C	804
3.2.3.2.2.2	CC2C	805
3.2.3.3	Resid Upgrading	805
3.2.3.3.1	Axens	805
3.2.3.3.2	Chevron Lummus Global	806
3.2.3.3.3	ExxonMobil	807
3.2.3.3.4	Honeywell UOP	808
3.3	<i>Refining R&D Alert!</i>	809
3.3.1	Introduction	809
3.3.2	Refinery-Petrochemical Integration	815
3.3.2.1	Maximizing Hydrocracker Naphtha	815
3.3.2.2	Converting LCO to Aromatics	817
3.3.2.2.1	Patents	817
3.3.2.2.2	Research	818
3.3.2.3	Cracking Heavy Olefins to Propylene	819
3.3.2.3.1	Patents	819
3.3.2.3.1.1	Process	819
3.3.2.3.1.2	Catalyst	821
3.3.2.3.2	Research	821
3.3.2.4	Propylene Production and Recovery	823
3.3.2.4.1	Petrochemical FCC	823
3.3.2.4.1.1	Patents	823
3.3.2.4.1.1.1	Process	823
3.3.2.4.1.1.1.1	Cracking of Oligomerized Feed	823
3.3.2.4.1.1.1.2	Dual Reactor FCCUs	825
3.3.2.4.1.1.1.3	Multi-stage Cracking	827
3.3.2.4.1.1.1.4	Downflow Reactor	828
3.3.2.4.1.1.1.5	Non-VGO Feedstocks	828
3.3.2.4.1.1.1.6	Integrated Process Schemes	830

3.3.2.4.1.1.1.7	Process Changes/Adjustments	830
3.3.2.4.1.1.2	Catalyst.....	832
3.3.2.4.1.1.2.1	ZSM-5	832
3.3.2.4.1.1.2.1.1	Incorporation of Phosphorus and/or Beta-zeolite	832
3.3.2.4.1.1.2.1.2	Addition of Transition Metal Components.....	833
3.3.2.4.1.1.2.1.3	Other Modifications	835
3.3.2.4.1.1.2.2	Other Zeolitic Catalysts	837
3.3.2.4.1.2	Research	839
3.3.2.4.1.2.1	Process	839
3.3.2.4.1.2.2	Catalyst.....	840
3.3.2.4.2	On-purpose Propylene Production.....	842
3.3.2.4.2.1	Metathesis.....	842
3.3.2.4.2.1.1	Patents	842
3.3.2.4.2.1.1.1	Process	842
3.3.2.4.2.1.1.1.1	Combined Isomerization and Metathesis	842
3.3.2.4.2.1.1.1.2	Multiple Stages.....	843
3.3.2.4.2.1.1.1.3	Feed Fractionation to Separate Components	844
3.3.2.4.2.1.1.1.4	Other	844
3.3.2.4.2.1.1.2	Catalyst.....	845
3.3.2.4.2.1.2	Research.....	846
3.3.2.4.2.2	Propane Dehydrogenation	847
3.3.2.4.2.2.1	Direct Dehydrogenation.....	847
3.3.2.4.2.2.1.1	Process	847
3.3.2.4.2.2.1.1.1	Hardware.....	847
3.3.2.4.2.2.1.1.2	Operation Improvements.....	848
3.3.2.4.2.2.1.1.3	Other	849
3.3.2.4.2.2.1.2	Catalyst.....	851
3.3.2.4.2.2.1.2.1	Pt-catalysts with or without Tin	851
3.3.2.4.2.2.1.2.2	Carrier Supports	855
3.3.2.4.2.2.1.2.3	Other	857
3.3.2.4.2.2.2	Oxidative Dehydrogenation	859
3.3.2.4.2.2.2.1	Process	859
3.3.2.4.2.2.2.2	Catalyst.....	859
3.3.2.4.2.3	Methanol-to-Olefins.....	861
3.3.2.4.2.3.1	Patents	861
3.3.2.4.2.3.1.1	Process	861
3.3.2.4.2.3.1.1.1	Operation Improvements.....	861
3.3.2.4.2.3.1.1.2	Other	862
3.3.2.4.2.3.1.2	Catalyst.....	864
3.3.2.4.2.3.2	Research.....	865
3.3.2.5	Aromatics Production and Recovery	869
3.3.2.5.1	Catalytic Reforming	869
3.3.2.5.1.1	Patents	869
3.3.2.5.1.2	Research.....	870
3.3.2.5.2	Aromatics from FCCU	871
3.3.2.5.2.1	Patents	871
3.3.2.5.2.2	Research.....	873
3.3.2.5.3	Disproportionation/Transalkylation.....	873
3.3.2.5.3.1	Patents	873
3.3.2.5.3.1.1	Process	873

3.3.2.5.3.1.2	Catalyst	877
3.3.2.5.3.2	Research	879
3.3.2.5.4	Xylene Isomerization and Recovery	880
3.3.2.5.4.1	Isomerization	880
3.3.2.5.4.1.1	Patents	880
3.3.2.5.4.1.1.1	Process	880
3.3.2.5.4.1.1.1.1	Preparation of Feedstock Prior to Isomerization	880
3.3.2.5.4.1.1.1.2	Dual-phase Processes	882
3.3.2.5.4.1.1.1.3	Heat Integration between Isomerization and Recovery Sections	883
3.3.2.5.4.1.1.1.4	Miscellaneous	884
3.3.2.5.4.1.1.2	Catalyst	885
3.3.2.5.4.1.2	Research	886
3.3.2.5.4.2	Separation and Purification of Xylene Isomers	886
3.3.2.5.4.2.1	Adsorption	886
3.3.2.5.4.2.1.1	Patents	886
3.3.2.5.4.2.1.1.1	Zeolitic Adsorbents	886
3.3.2.5.4.2.1.1.2	Integration with Fractionation	887
3.3.2.5.4.2.1.1.3	Miscellaneous	888
3.3.2.5.4.2.1.2	Research	889
3.3.2.5.4.2.2	Crystallization	892
3.3.2.5.4.2.3	Combined Adsorption and Crystallization	894
3.3.2.5.5	Recovery of Aromatics by Extraction, Extractive Distillation, or Distillation	895
3.3.2.5.5.1	Patents	895
3.3.2.5.5.2	Research	897
3.3.3	Crude-to-Chemicals	898
3.3.3.1	Direct Crude Cracking	898
3.3.3.2	Refinery Reconfiguration	899
3.4	References	902
4.	LATEST REFINING TECHNOLOGY DEVELOPMENTS & LICENSING	921
4.1	Fluid Catalytic Cracking	921
4.2	Isomerization	921
4.3	Alkylation	922
4.4	Hydrogen Production and Purification	922
4.5	Lube Production	923
4.6	Process Controls and Simulation	923
4.7	Internet of Things (IoT)	924
4.8	Biofuels Production	929
4.9	Energy Management	930
4.10	CO ₂ Emissions (Carbon Capture and Sequestration)	931
4.11	References	932