

TECHNOLOGY & COSTS**Technoeconomics - Energy & Chemicals (TECH)****TECH 2020-4 Phenol/Acetone/Cumene**

Table of Contents

A Report by **NexantECA**

Published Date: August 2020

www.nexanteca.com/subscriptions-and-reports**Contents**

1	Executive Summary	1
1.1	Overview.....	1
1.2	Technology Licensors	1
1.3	Technology Developments.....	2
1.4	Strategic and Business Considerations	2
1.5	Economic Analysis	3
1.6	Market Analysis	7
1.6.1	Commercial Applications.....	7
1.6.2	Supply and Demand Analysis	8
2	Introduction.....	12
2.1	Value Chain.....	12
2.2	Cumene.....	12
2.2.1	Technology Overview.....	12
2.2.2	Technology Developments.....	13
2.2.3	Technology Licensors and Major Producers.....	13
2.2.4	Strategic and Business Considerations	14
2.2.5	Physical and Thermodynamic Properties	15
2.2.6	Specifications	15
2.2.7	Health Hazards.....	16
2.2.8	Storage and Transportation	16
2.3	Phenol	17
2.3.1	Technology Overview.....	17
2.3.2	Technology Developments.....	18
2.3.3	Technology Licensors and Major Producers.....	18
2.3.4	Strategic and Business Considerations	19
2.3.5	Physical and Thermodynamic Properties	20
2.3.6	Specifications	21
2.3.7	Health Hazards.....	21
2.3.8	Storage and Transportation	22
2.4	Acetone	22
2.4.1	Technology Overview.....	22

2.4.2	Technology Developments	22
2.4.3	Technology Licensors and Major Producers	23
2.4.4	Strategic and Business Considerations	24
2.4.5	Physical and Thermodynamic Properties	25
2.4.6	Specifications	26
2.4.7	Health Hazards	26
2.4.8	Storage and Transportation	27
3	Cumene Commercial Technologies	28
3.1	Chemistry	28
3.2	Catalyst Comparison	31
3.3	Badger Licensing	33
3.3.1	Background	33
3.3.2	Process Features	33
3.3.3	Process Description	33
3.3.4	Operating Performance	35
3.4	Honeywell UOP	35
3.4.1	Background	35
3.4.2	Process Features	35
3.4.3	Process Description	36
3.4.4	Operating Performance	38
3.5	Versalis/Lummus Technology	38
3.5.1	Background	38
3.5.2	Process Features	39
3.5.3	Process Description	42
3.5.4	Operating Performance	44
4	Phenol and Acetone Commercial Technologies	45
4.1	Chemistry	45
4.1.1	Cumene Oxidation to Cumene Hydroperoxide	46
4.1.2	Cumene Hydroperoxide Cleavage to Phenol and Acetone	48
4.2	Generic Technology Overview	50
4.2.1	Oxidation	50
4.2.2	Cumene Hydroperoxide Concentration (Cumene Stripping)	54
4.2.3	Cumene Hydroperoxide Cleavage	54
4.2.4	Neutralization	55
4.2.5	Product Recovery and α -Methylstyrene Hydrogenation	55
4.3	Honeywell UOP	56
4.3.1	Background	56
4.3.2	Process Features	56
4.3.3	Process Description	56
4.3.4	Operating Performance	59
4.4	ILLA International	60
4.4.1	Background	60
4.4.2	Process Features	60
4.4.3	Process Description	61
4.4.4	Operating Performance	65

4.5	KBR	67
4.5.1	Background	67
4.5.2	Process Features	68
4.5.3	Process Description	69
4.5.4	Operating Performance Data	73
4.6	Mitsui Chemicals	74
4.6.1	Background	74
4.6.2	Process Features	74
4.6.3	Process Description	75
4.6.4	Operating Performance	77
4.7	Versalis/Lummus Technology	78
4.7.1	Background	78
4.7.2	Process Features	78
4.7.3	Process Description	79
4.7.4	Operating Performance	82
5	Developing or Alternative Technologies.....	83
5.1	Introduction.....	83
5.2	Selected Recent Patents.....	83
5.3	Cumene via Alkylation of Benzene and Isopropanol	87
5.3.1	Badger Licensing.....	87
5.3.2	Versalis.....	87
5.4	Cumene via Alkylation of Benzene and Acetone	88
5.5	Phenol via Cyclohexylbenzene Oxidation	88
5.5.1	Cyclohexylbenzene via Hydroalkylation of Benzene	89
5.5.2	Phenol via Cyclohexylbenzene Oxidation	89
5.6	Green Technologies.....	92
5.6.1	Bio-derived Cumene and Phenol	92
5.6.2	Bio-derived Acetone	92
6	Historical Processes.....	95
6.1	Phenol via Benzene Oxidation with Nitrous Oxide	95
6.1.1	On-Purpose Nitrous Oxide with Ammonia	96
6.1.2	Phenol via Benzene Oxidation with Nitrous Oxide	98
6.2	Phenol via Benzene Oxidation with Hydrogen Peroxide or Hydrogen/Oxygen	101
6.2.1	Council of Scientific and Industrial Research.....	101
6.2.2	General Electric.....	101
6.2.3	Versalis.....	101
6.3	Phenol via Hydrolysis of Bromobenzene	102
6.3.1	Microvast Power Systems.....	102
6.4	Phenol with Methyl Ethyl Ketone and Acetone Coproducts.....	102
6.4.1	ExxonMobil.....	103
6.4.2	Shell.....	104
6.5	Phenol via Toluene Oxidation	106
6.5.1	Benzoic Acid Synthesis and Purification	106
6.5.2	Phenol Synthesis and Purification.....	108
7	Process Economics	111

7.1	Costing Basis	111
7.1.1	Investment Basis	111
7.1.2	Pricing Basis.....	111
7.1.3	Cost of Production Basis	113
7.2	Production Cost Estimates	114
7.2.1	Cost of Producing Cumene via Alkylation of Benzene with Propylene using a Zeolite Catalyst	114
7.2.2	Cost of Producing Phenol (with Acetone Byproduct) via Cumene Oxidation and CHP Cleavage (Conventional Process).....	122
7.2.3	Cost of Producing Phenol from Benzene and Propylene with Acetone Recycle (Mitsui Process).....	131
7.2.4	Speculative Cost of Producing Phenol via the Hydroalkylation of Benzene (Developing Process).....	135
7.3	Comparison of Commercial Processes to Produce Phenol	143
7.4	Comparison of the Conventional and Developing Phenol Technologies	149
7.5	Sensitivity Analysis.....	150
7.5.1	Sensitivity to Feed Pricing	150
7.5.2	Sensitivity to Capital Investment	151
7.5.3	Sensitivity to Economy of Scale	151
7.6	Historical Analysis of Phenol Cash Cost Production	152
7.7	Return on Investment and Investment Attractiveness	153
8	Commercial Applications	155
8.1	Cumene	155
8.2	Phenol	155
8.2.1	Bisphenol A	156
8.2.2	Phenolic Resins.....	157
8.2.3	Caprolactam	158
8.2.4	Adipic Acid.....	159
8.2.5	Plasticizers	160
8.2.6	Aniline.....	160
8.2.7	Acetylsalicylic Acid	160
8.3	Acetone	160
8.3.1	Methyl Methacrylate	161
8.3.2	Methyl Isobutyl Ketone	162
8.3.3	Isopropanol.....	162
9	Regional Market Analysis	163
9.1	Cumene	163
9.1.1	Global	163
9.1.2	North America	166
9.1.3	Western Europe	169
9.1.4	Asia Pacific.....	171
9.2	Phenol	175
9.2.1	Global	175
9.2.2	North America	178
9.2.3	Western Europe	182
9.2.4	Asia Pacific.....	185

9.3	Acetone	189
9.3.1	Global	189
9.3.2	North America	192
9.3.3	Western Europe	195
9.3.4	Asia Pacific	198
10	Glossary	202

Appendices

A	Definitions of Capital Cost Terms Used in Process Economics	206
B	Definitions of Operating Cost Terms Used in Process Economics	211
C	TECH Program Title Index (2010-2020)	214

Figures

Figure 1	Cumene-Phenol-Acetone Value Chain	1
Figure 2	U.S. Gulf Coast Summary of Phenol Production Costs	4
Figure 3	Western Europe Summary of Phenol Production Costs	4
Figure 4	China Summary of Phenol Production Costs	5
Figure 5	Japan Summary of Phenol Production Costs	5
Figure 6	Southeast Asia Summary of Phenol Production Costs	6
Figure 7	Summary of Phenol Production Costs	6
Figure 8	Global Cumene Supply, Demand, and Trade Balance	8
Figure 9	Global Phenol Supply, Demand, and Trade Balance	10
Figure 10	Global Acetone Supply, Demand, and Trade Balance	11
Figure 11	Cumene-Phenol-Acetone Value Chain	12
Figure 12	Major Producers of Cumene, 2019	14
Figure 13	Major Producers of Phenol, 2019	19
Figure 14	Major Producers of Acetone, 2019	24
Figure 15	Overview of Cumene Process Chemistry	28
Figure 16	Transalkylation Chemistry	29
Figure 17	Badger Cumene Technology Process	34
Figure 18	Honeywell UOP Q-Max™ Process	37
Figure 19	Versalis/Lummus Cumene Process	43
Figure 20	Overview of Phenol Process Chemistry	45
Figure 21	Cumene Oxidation and Cleavage	51
Figure 22	Phenol/Acetone Recovery and AMS Hydrogenation	52
Figure 23	Honeywell UOP Phenol Process	57
Figure 24	ILLA Phenol/Acetone Process	62
Figure 25	KBR Improvements in the Phenol Process	69
Figure 26	KBR Phenol Process	70
Figure 27	Mitsui Acetone Recycle Technology Chemistry	74
Figure 28	Mitsui Acetone Recycle Process	76
Figure 29	Versalis/Lummus Phenol Process	80
Figure 30	Honeywell UOP Phenol and Acetone Purification Process	84
Figure 31	ExxonMobil Phenol and Cyclohexanone Process	91
Figure 32	ABE Metabolic Pathway	93
Figure 33	ABE Process Schematic	94
Figure 34	Phenol from Benzene Oxidation with Nitrous Oxide	95
Figure 35	Solutia/BIC On-Purpose Nitrous Oxide Production using Fluid Bed Reactor Process	97
Figure 36	Solutia/BIC Benzene to Phenol Process	100
Figure 37	Phenol via Toluene-Benzoic Acid Synthesis and Purification	107
Figure 38	Phenol via Toluene-Phenol Synthesis and Purification	109
Figure 39	Summary of Cumene via the Alkylation of Benzene with Propylene (Zeolite Catalyst) Process Production Costs	122
Figure 40	Summary of Phenol with Acetone Byproduct) via Cumene Oxidation and CHP Cleavage (Conventional Process) Production Cost	130
Figure 41	Summary of Phenol from Benzene and Propylene with Acetone Recycle (Mitsui) Process Production Cost	134
Figure 42	Summary of Phenol via the Hydroalkylation of Benzene (Developing Process) Production Costs	142
Figure 43	U.S. Gulf Coast Summary of Phenol Production Costs	143
Figure 44	Western Europe Summary of Phenol Production Costs	144

Figure 45	China Summary of Phenol Production Costs	145
Figure 46	Japan Summary of Phenol Production Costs.....	146
Figure 47	Southeast Asia Summary of Phenol Production Costs	147
Figure 48	Summary of Phenol Production Costs	148
Figure 49	Regional Cyclohexanone Trade Prices	149
Figure 50	Sensitivity of Phenol Costs of Production to Feed Price	150
Figure 51	Sensitivity of Phenol Costs of Production to Capital Investment.....	151
Figure 52	Sensitivity of Phenol Costs of Production to Economy of Scale	152
Figure 53	Historical Phenol Production Cash Costs.....	153
Figure 54	ROI versus Capital Intensity of Phenol Plants.....	154
Figure 55	Cumene Value Chain	155
Figure 56	Phenol Value Chain	155
Figure 57	Acetone Value Chain	161
Figure 58	Global Cumene Demand by End Use, 2019-e	163
Figure 59	Global Cumene Demand by Region, 2019-e	164
Figure 60	Global Cumene Capacity by Region, 2019-e	164
Figure 61	Global Cumene Supply, Demand, and Trade Balance	165
Figure 62	North American Cumene Demand by End Use, 2019-e	166
Figure 63	North American Cumene Supply, Demand, and Trade Balance.....	168
Figure 64	Western Europe Cumene Demand by End Use, 2019-e	169
Figure 65	Western Europe Cumene Supply, Demand, and Trade Balance	171
Figure 66	Asia Pacific Cumene Demand by End Use, 2019-e	171
Figure 67	Asia Pacific Cumene Supply, Demand, and Trade Balance	175
Figure 68	Global Phenol Demand by End Use, 2019-e	175
Figure 69	Global Phenol Demand by Region, 2019-e	176
Figure 70	Global Phenol Capacity by Region, 2019-e	177
Figure 71	Global Phenol Supply, Demand, and Trade Balance	178
Figure 72	North American Phenol Demand by End Use, 2019-e.....	179
Figure 73	North American Phenol Supply, Demand, and Trade Balance	181
Figure 74	Western Europe Phenol Demand by End Use, 2019-e.....	182
Figure 75	Western Europe Phenol Supply, Demand, and Trade Balance	184
Figure 76	Asia Pacific Phenol Demand by End Use, 2019-e	185
Figure 77	Asia Pacific Phenol Supply, Demand, and Trade Balance	188
Figure 78	Global Acetone Demand by End Use, 2019-e	189
Figure 79	Global Acetone Demand by Region, 2019-e	190
Figure 80	Global Acetone Capacity by Region, 2019-e	190
Figure 81	Global Acetone Supply, Demand, and Trade Balance.....	191
Figure 82	North American Acetone Demand by End Use, 2019-e.....	192
Figure 83	North American Acetone Supply, Demand, and Trade Balance	194
Figure 84	Western Europe Acetone Demand by End Use, 2019-e.....	195
Figure 85	Western Europe Acetone Supply, Demand, and Trade Balance	197
Figure 86	Asia Pacific Acetone Demand by End Use, 2019-e	198
Figure 87	Asia Pacific Acetone Supply, Demand, and Trade Balance	201

Tables

Table 1	Current Licensor Offerings	2
Table 2	Strategic/Business Considerations	3
Table 3	Cumene Technology Licensors	13
Table 4	Strategic/Business Considerations for the Cumene Industry	14
Table 5	Key Physical and Thermodynamic Properties of Cumene	15
Table 6	Sale Specifications for Cumene	16
Table 7	Highlights in the Development of Phenol Production Technology	17
Table 8	Phenol Technology Licensors	18
Table 9	Strategic/Business Considerations for the Phenol Industry	20
Table 10	Key Physical and Thermodynamic Properties of Phenol	21
Table 11	Sale Specifications for Phenol	21
Table 12	Acetone Technology Licensors	23
Table 13	Strategic/Business Considerations for the Acetone Industry	25
Table 14	Key Physical and Thermodynamic Properties of Acetone	25
Table 15	Sale Specifications for Acetone	26
Table 16	Typical Propylene Feedstock Specifications	30
Table 17	Benzene Feedstock Specifications	30
Table 18	Catalyst Comparison - Typical Operating Conditions & Cumene Specifications	32
Table 19	Honeywell UOP Cumene Performance Data	38
Table 20	Honeywell UOP Q-Max™ Cumene Specifications	38
Table 21	Versalis/Lummus Cumene Performance Data	44
Table 22	Versalis/Lummus Cumene Specifications	44
Table 23	Honeywell UOP Phenol Performance Data	59
Table 24	Honeywell UOP Phenol Specifications	59
Table 25	Honeywell UOP Acetone Specifications	60
Table 26	ILLA International Phenol Performance Data	65
Table 27	ILLA Phenol Specifications	66
Table 28	ILLA Acetone Specifications	66
Table 29	Grassroots Phenol Plants Employing Licensed KBR Phenol Technology Since 2000	67
Table 30	KBR Phenol Performance Data	73
Table 31	KBR Phenol Specifications	73
Table 32	Mitsui Acetone Recycle Process Performance Data	77
Table 33	Propylene Product Quality for Mitsui Acetone Performance Data	77
Table 34	Versalis/Lummus Performance Data	82
Table 35	Versalis/Lummus Phenol Specifications	82
Table 36	Versalis/Lummus Acetone Performance Data	82
Table 37	Experimental Results	86
Table 38	Prices of Raw Materials, Products, Utilities, and Labor	112
Table 39	Cost of Production Estimate for: Cumene Process: Alkylation of Benzene with Propylene (Zeolite Catalyst); USGC Basis	116
Table 40	Cost of Production Estimate for: Cumene Process: Alkylation of Benzene with Propylene (Zeolite Catalyst); Western Europe Basis	117
Table 41	Cost of Production Estimate for: Cumene Process: Alkylation of Benzene with Propylene (Zeolite Catalyst); China Basis	118
Table 42	Cost of Production Estimate for: Cumene Process: Alkylation of Benzene with Propylene (Zeolite Catalyst); Japan Basis	119

Table 43	Cost of Production Estimate for: Cumene Process: Alkylation of Benzene with Propylene (Zeolite Catalyst); Southeast Asia Basis.....	120
Table 44	Summary of Cumene via the Alkylation of Benzene with Propylene (Zeolite Catalyst) Process Production Costs.....	121
Table 45	Optimal Yields in Phenol Production	122
Table 46	Material Balance for Cumene to Phenol Process.....	123
Table 47	Cost of Production Estimate for: Phenol (with Acetone Byproduct) Process: Cumene Oxidation and CHP Cleavage; USGC Basis	125
Table 48	Cost of Production Estimate for: Phenol (with Acetone Byproduct) Process: Cumene Oxidation and CHP Cleavage; Western Europe Basis.....	126
Table 49	Cost of Production Estimate for: Phenol (with Acetone Byproduct) Process: Cumene Oxidation and CHP Cleavage; China Basis	127
Table 50	Cost of Production Estimate for: Phenol (with Acetone Byproduct) Process: Cumene Oxidation and CHP Cleavage; Japan Basis	128
Table 51	Cost of Production Estimate for: Phenol (with Acetone Byproduct) Process: Cumene Oxidation and CHP Cleavage; Southeast Asia Basis.....	129
Table 52	Summary of Phenol with Acetone Byproduct) via Cumene Oxidation and CHP Cleavage (Conventional Process) Production Cost	130
Table 53	Cost of Production Estimate for: Phenol Process: from Benzene and Propylene with Acetone Recycle (Mitsui); USGC Basis	132
Table 54	Cost of Production Estimate for: Phenol Process: from Benzene and Propylene with Acetone Recycle (Mitsui); Japan Basis.....	133
Table 55	Summary of Phenol from Benzene and Propylene with Acetone Recycle (Mitsui Process) Production Cost.....	134
Table 56	Cost of Production Estimate for: Phenol Process: Hydroalkylation of Benzene; USGC Basis	137
Table 57	Cost of Production Estimate for: Cumene Process: Hydroalkylation of Benzene; Western Europe Basis.....	138
Table 58	Cost of Production Estimate for: Cumene Process: Hydroalkylation of Benzene; China Basis	139
Table 59	Cost of Production Estimate for: Cumene Process: Hydroalkylation of Benzene; Japan Basis	140
Table 60	Cost of Production Estimate for: Cumene Process: Hydroalkylation of Benzene; Southeast Asia Basis	141
Table 61	Summary of Phenol via the Hydroalkylation of Benzene (Developing Process) Production Costs	142
Table 62	U.S. Gulf Coast Summary of Phenol Production Costs	143
Table 63	Western Europe Summary of Phenol Production Costs	144
Table 64	China Summary of Phenol Production Costs	145
Table 65	Japan Summary of Phenol Production Costs.....	146
Table 66	Southeast Asia Summary of Phenol Production Costs	147
Table 67	ROI versus Capital Intensity of Phenol Plants.....	154
Table 68	Global Cumene Supply, Demand, and Trade Balance	165
Table 69	North American Cumene Capacity, 2019-e.....	167
Table 70	North American Cumene Supply, Demand, and Trade Balance.....	168
Table 71	Western Europe Cumene Capacity, 2019-e.....	170
Table 72	Western Europe Cumene Supply, Demand, and Trade Balance.....	170
Table 73	Asia Pacific Cumene Capacity, 2019-e	173
Table 74	Asia Pacific Cumene Supply, Demand, and Trade Balance	174
Table 75	Global Phenol Supply, Demand, and Trade Balance.....	177

Table 76	North American Phenol Capacity, 2019-e	180
Table 77	North American Phenol Supply, Demand, and Trade Balance	181
Table 78	Western Europe Phenol Capacity, 2019-e	183
Table 79	Western Europe Phenol Supply, Demand, and Trade Balance	184
Table 80	Asia Pacific Phenol Capacity, 2019-e	187
Table 81	Asia Pacific Phenol Supply, Demand, and Trade Balance	188
Table 82	Global Acetone Supply, Demand, and Trade Balance	191
Table 83	North American Acetone Capacity, 2019-e	193
Table 84	North American Acetone Supply, Demand, and Trade Balance	194
Table 85	Western Europe Acetone Capacity, 2019-e	196
Table 86	Western Europe Acetone Supply, Demand, and Trade Balance	197
Table 87	Asia Pacific Acetone Capacity, 2019-e	200
Table 88	Asia Pacific Acetone Supply, Demand, and Trade Balance	201



TECHNOLOGY & COSTS

Technoeconomics - Energy & Chemicals (TECH)

The NexantECA 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: NexantECA Subscriptions
Phone: + 1-914-609-0324, e-mail: mcesar@nexantECA.com

Erica Hill, Client Services Coordinator, E&CA-Products
Phone: + 1-914-609-0386, e-mail: ehill@nexantECA.com

EMEA:

Anna Ibbotson, Director, NexantECA Subscriptions
Phone: +44-207-950-1528, aibbotson@nexantECA.com

Asia:

Chommanad Thammanayakatip, Managing Consultant, Energy & Chemicals Advisory
Phone: +66-2793-4606, email: chommanadt@nexantECA.com

NexantECA (www.nexantECA.com) is a leading management consultancy to the global energy, chemical, and related industries. For over 38 years, NexantECA 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. NexantECA has its main offices in White Plains (New York), and London (UK), and satellite offices worldwide.

Copyright © by NexantECA 2020. All Rights Reserved.