

TECHNOLOGY & COSTS**Technoeconomics - Energy & Chemicals (TECH)****TECH 2023-5 Methyl Methacrylate (MMA)**

Table of Contents

A Report by **NexantECA**, the Energy and Chemical Advisory company

Published Date: October 2023

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

1	Executive Summary	1
1.1	Overview.....	1
1.2	Technology Overview.....	2
1.3	Strategic and Business Considerations	4
1.4	Economic Analysis	5
1.5	Carbon Intensity Analysis.....	6
1.5.1	United States.....	6
1.5.2	Western Europe	7
1.5.3	China	8
1.6	Commercial Applications.....	8
1.6.1	End-Use Applications.....	8
1.7	Supply Analysis	9
2	Introduction.....	11
2.1	Overview.....	11
2.2	Value Chain.....	12
2.3	Technology Developments.....	13
2.3.1	Technology Comparisons	15
2.4	Technology Holders and Licensing Status.....	17
2.5	Strategic and Business Considerations	18
2.6	Physical and Thermodynamic Properties.....	19
2.7	Specifications	20
2.8	Health Hazards.....	20
2.9	Storage and Transportations.....	20
3	Commercial Technologies.....	21
3.1	Introduction.....	21
3.2	Acetone Cyanohydrin Route	25
3.2.1	Background and Chemistry.....	25
3.2.2	Acetone Cyanohydrin Production.....	30
3.2.3	Hydrolysis and Esterification of ACH	32

3.2.4	Methyl Methacrylate Product Recovery and Purification	34
3.2.5	Sulfuric Acid Recovery	37
3.3	Isobutylene (or Tertiary Butyl Alcohol) Gas-Phase Oxidation Route	40
3.3.1	Background and Sources of Isobutylene (i-C4) and Tertiary Butyl Alcohol (TBA)	40
3.3.2	Chemistry of Isobutylene Route	41
3.3.3	Oxidation of Isobutylene.....	43
3.3.4	Methacrylic Acid Recovery	45
3.3.5	Methacrylic Acid Esterification and Methyl Methacrylate Recovery.....	47
3.3.6	Tertiary-Butyl Alcohol Route	49
3.4	Mitsubishi's Alpha Process.....	50
3.4.1	Background	50
3.4.2	Chemistry	52
3.4.3	Process Description	57
3.5	Other Commercial Routes.....	63
3.5.1	Asahi Kasei Corporation "Direct Oxidative Esterification (DOE)" Route	63
3.5.2	BASF Route	64
3.5.3	Mitsubishi Gas Chemical Hydrogen Cyanide (HCN) Recycle Route.....	66
3.5.4	LiMA® Process.....	68
4	Developing Technologies	78
4.1	Patent Analysis.....	78
4.2	Biorenewable Routes	81
4.2.1	Biomass Gasification for Methanol Production	83
4.2.2	Bio-acetone Production	84
4.2.3	Bio-Isobutylene Production	85
4.2.4	Production of Methyl Propionate via Enzymes	85
4.2.5	Bio-ethanol to Ethylene Production.....	85
4.2.6	Bio-based Propylene Production.....	86
4.3	Methyl Methacrylate Production from PMMA Recycling	91
4.3.1	Polymethyl Methacrylate Depolymerization Technologies.....	91
4.3.2	High Level Profiles of Selected Technology Developers	93
5	Economic Analysis	94
5.1	Costing Basis	94
5.1.1	Investment Basis	94
5.1.2	Pricing Basis.....	94
5.1.3	Cost of Production Basis.....	96
5.2	Production Cost Estimates	96
5.2.1	Cost of Producing MMA via the ACH Route	97
5.2.2	Cost of Producing MMA via the Isobutylene (i-C4) Route	104
5.2.3	Cost of Producing MMA via Mitsubishi Chemical Group via Alpha Technology	111
5.3	Regional Cost Competitiveness	118
5.4	Historical Analysis of MMA Cash Cost of Production	120

5.4.1	ACH Route	122
5.4.2	Isobutylene Route	123
5.4.3	Alpha Technology	125
5.4.4	Investment Analysis Conclusions	126
5.5	Return on Investment and Investment Attractiveness	127
6	Carbon Intensity Analysis	129
6.1	Basis	129
6.1.1	Carbon Intensity Reduction	129
6.1.2	Carbon Intensity Methodology	130
6.2	Carbon Dioxide Emissions	134
6.2.1	The United States	135
6.2.2	Western Europe	136
6.2.3	China	137
7	Commercial Applications	138
7.1	PMMA	139
7.2	Surface Coatings	139
7.3	Others	139
8	MMA Capacity Analysis	140
8.1	Types of Developments	140
8.2	Existing Capacity	140
8.2.1	North America	140
8.2.2	Western Europe	141
8.2.3	Middle East	141
8.2.4	China	141
8.2.5	Asia Pacific (excluding China)	144

Appendices

A	Supporting Cost of Production Estimates	146
B	Definitions of Capital Cost Terms Used in Process Economics	166
C	Definitions of Operating Cost Terms Used in Process Economics	170
D	References	173

Figures

Figure 1	MMA Value Chain.....	1
Figure 2	ROCE Comparisons for MMA Processes	5
Figure 3	MMA Production Technologies Carbon Intensity Comparison, United States	6
Figure 4	MMA Production Technologies Carbon Intensity Calculation, Western Europe	7
Figure 5	MMA Production Technologies Carbon Intensity Calculation, China	8
Figure 6	Global Capacity by Region	9
Figure 7	Global MMA Capacity Share, 1Q 2023	10
Figure 8	Example Uses of PMMA.....	11
Figure 9	MMA Value Chain.....	12
Figure 10	Overview of Major MMA Process Feedstocks.....	13
Figure 11	Routes to MMA	15
Figure 12	Global MMA Capacity by Technology (2023)	17
Figure 13	Simplified Block Diagram of ACH Route	21
Figure 14	Simplified Block Diagram of i-C ₄ Route	21
Figure 15	Simplified Block Diagram of Mitsubishi Alpha Process	22
Figure 16	Simplified Block Diagram of BASF Route	22
Figure 17	Simplified Block Diagram of Asahi “DOE” Route.....	23
Figure 18	Simplified Block Diagram of MGC HCN Recycle Route.....	23
Figure 19	Simplified Block Diagram of LiMA [®] Process	24
Figure 20	MMA via ACH Process – ACH Production and Purification	31
Figure 21	MMA via ACH Process – Hydrolysis and Esterification.....	33
Figure 22	MMA via ACH Process – Product Recovery and Purification	35
Figure 23	Sulfuric Acid Recovery	38
Figure 24	MMA via i-C ₄ Oxidation Process – Oxidation of Isobutylene.....	44
Figure 25	MMA via i-C ₄ Oxidation Process – Methacrylic Acid Recovery.....	46
Figure 26	MMA via i-C ₄ Oxidation Process – Esterification and MMA Recovery.....	48
Figure 27	Alpha Process Block Flow Diagram	51
Figure 28	Lucite-Alpha Process - Carbonylation Reaction and Formaldehyde Dewatering Sections	53
Figure 29	Lucite Alpha Process – Catalyst Recovery and Regeneration.....	54
Figure 30	Lucite Alpha Process – Condensation Reaction and Crude MMA Separation Sections	55
Figure 31	Lucite Alpha Process – Finishing Section	56
Figure 32	Block Flow Diagram of the LiMA [®] Process	69
Figure 33	Simplified Block Diagram including Recovery and Purification Section for LiMA [®] Process.....	69
Figure 34	Step A of LiMA Process -Condensation Reaction.....	70
Figure 35	Evonik LiMA [®] Process – Step A: Production of Methacrolein.....	71
Figure 36	Evonik LiMA [®] Process – Step B: Production of MMA	74
Figure 37	Regional Patent Activity from January 2018 to July 2023.....	78
Figure 38	Patent Developments by Topic (January 2018 to December 2022)	79

Figure 39	Patent Activities by Key MMA Players	79
Figure 40	Bio Routes to MMA.....	82
Figure 41	AVE Metabolic Pathway	84
Figure 42	Bio-Ethanol to Green Ethylene: Conceptual Process Flow	86
Figure 43	Routes to Bio-Propylene.....	87
Figure 44	PMMA Depolymerization Mechanism	91
Figure 45	Cost of Production Summary for MMA via ACH Route	98
Figure 46	Cost of Production Summary for MMA via Isobutylene Route	105
Figure 47	Cost of Production Summary for MMA via Alpha Technology	112
Figure 48	Regional Costs of Production for MMA Processes	118
Figure 49	Regional Market Prices (China).....	120
Figure 50	Historical MMA Production Cash Costs - China.....	121
Figure 51	Cost of Production and ROCE Comparison for ACH Route	122
Figure 52	Acetone, Methanol and MMA Price Trends.....	123
Figure 53	Cost of Production and ROCE Comparison for iso-Butylene (i-C ₄) Route.....	124
Figure 54	MTBE and MMA Price Trends.....	124
Figure 55	Cost of Production and ROCE Comparison for Alpha Process	125
Figure 56	Ethylene and MMA Price Trends.....	126
Figure 57	ROCE Comparison for MMA Processes	127
Figure 58	Return on Investment versus Capital Intensity of MMA Plants	128
Figure 59	Definitions of Scope Emissions	131
Figure 60	Process Carbon Balance	131
Figure 61	Equation for Raw Material Emissions.....	132
Figure 62	Equation for Utility Emissions	133
Figure 63	MMA Production Technologies Carbon Intensity Comparison, United States	135
Figure 64	MMA Production Technologies Carbon Intensity Calculation, Western Europe	136
Figure 65	MMA Production Technologies Carbon Intensity Calculation, China.....	137
Figure 66	Global MMA Demand by End Use, 2023	138

Tables

Table 1	Summary of Commercial MMA Technologies	2
Table 2	Strategic and Business Considerations.....	4
Table 3	Technology Comparisons of MMA Processes	16
Table 4	MMA Licensors and Technology Holders.....	17
Table 5	Strategic and Business Considerations.....	18
Table 6	Key Physical and Thermodynamic Properties.....	19
Table 7	Typical Commercial Specifications for Methyl Methacrylate Grade	20
Table 8	LiMA Process Step A Comparison with BASF Route	76
Table 9	LiMA Process Step B Comparison to Asahi's "Direct Metha" Process	77
Table 10	Key Player Patent Activity (January 2018 to July 2023)	80
Table 11	PMMA Depolymerization Technologies	92
Table 12	Polymethyl Methacrylate Depolymerization Technology Developers	93
Table 13	Prices of Raw Materials, Products, Utilities, and Labor.....	95
Table 14	Material Balance for MMA via the ACH Route	97
Table 15	Cost of Production Summary for MMA via the ACH Route	98
Table 16	Cost of Production Estimate for: MMA Process: ACH Route; U.S. Gulf Coast Basis	99
Table 17	Cost of Production Estimate for: MMA Process: ACH Route; Western Europe Basis	100
Table 18	Cost of Production Estimate for: MMA Process: ACH Route; China Basis	101
Table 19	Cost of Production Estimate for: MMA Process: ACH Route; Japan Basis.....	102
Table 20	Cost of Production Estimate for: MMA Process: ACH Route; Southeast Asia Basis	103
Table 21	Material Balance for MMA via the Isobutylene Route	104
Table 22	Cost of Production Summary for MMA via the Isobutylene (i-C ₄) Route.....	104
Table 23	Cost of Production Estimate for: MMA-Isobutylene Process: Isobutylene (i-C ₄) Oxidation Route; U.S. Gulf Coast Basis	106
Table 24	Cost of Production Estimate for: MMA-Isobutylene Process: Isobutylene (i-C ₄) Oxidation Route; Western Europe Basis	107
Table 25	Cost of Production Estimate for: MMA-Isobutylene Process: Isobutylene (i-C ₄) Oxidation Route; China Basis.....	108
Table 26	Cost of Production Estimate for: MMA-Isobutylene Process: Isobutylene (i-C ₄) Oxidation Route; Japan Basis	109
Table 27	Cost of Production Estimate for: MMA-Isobutylene Process: Isobutylene (i-C ₄) Oxidation Route; Southeast Asia Basis.....	110
Table 28	Material Balance for MMA via Alpha Technology.....	111
Table 29	Cost of Production Summary for MMA via Alpha Technology	111
Table 30	Cost of Production Estimate for: MMA-Lucite Process: Lucite Alpha Methyl Propionate Route; USGC Basis.....	113
Table 31	Cost of Production Estimate for: MMA-Lucite Process: Lucite Alpha Methyl Propionate Route; Western Europe Basis	114

Table 32	Cost of Production Estimate for: MMA-Lucite Process: Lucite Alpha Methyl Propionate Route; China Basis.....	115
Table 33	Cost of Production Estimate for: MMA-Lucite Process: Lucite Alpha Methyl Propionate Route; Japan Basis	116
Table 34	Cost of Production Estimate for: MMA-Lucite Process: Lucite Alpha Methyl Propionate Route; Southeast Asia Basis.....	117
Table 35	Return on Investment versus Capital Intensity of MMA Plants	128
Table 36	Grid Energy Mix across all Regions	133
Table 37	MMA Production Technologies Carbon Intensity Comparison, United States.....	135
Table 38	MMA Production Technologies Carbon Intensity Comparison, Western Europe	136
Table 39	MMA Production Technologies Carbon Intensity Comparison, China	137
Table 40	North America MMA Capacity, 2023	140
Table 41	Western Europe MMA Capacity, 2023	141
Table 42	Middle East MMA Capacity, 2023	141
Table 43	China MMA Capacity, 2023.....	142
Table 44	Asia Pacific (excluding China) MMA Capacity	144
Table 45	Cost of Production Estimate for: Hydrogen Cyanide Process: Andrussov, USGC Basis.....	146
Table 46	Cost of Production Estimate for: Hydrogen Cyanide Process: Andrussov, Western Europe Basis.....	147
Table 47	Cost of Production Estimate for: Hydrogen Cyanide Process: Andrussov, China Coast Basis	148
Table 48	Cost of Production Estimate for: Hydrogen Cyanide Process: Andrussov, Japan Basis	149
Table 49	Cost of Production Estimate for: Hydrogen Cyanide Process: Andrussov, Southeast Asia Basis.....	150
Table 50	Cost of Production Estimate for: Isobutylene Process: MTBE Cracking, USGC Basis	151
Table 51	Cost of Production Estimate for: Isobutylene Process: MTBE Cracking, Western Europe Basis	152
Table 52	Cost of Production Estimate for: Isobutylene Process: MTBE Cracking, China Coast Basis.....	153
Table 53	Cost of Production Estimate for: Isobutylene Process: MTBE Cracking, Japan Basis.....	154
Table 54	Cost of Production Estimate for: Isobutylene Process: MTBE Cracking, Southeast Asia Basis	155
Table 55	Cost of Production Estimate for: Synthesis Gas, H ₂ /CO= 1/1 Process: Methane Steam Reforming, USGC Basis	156
Table 56	Cost of Production Estimate for: Synthesis Gas, H ₂ /CO= 1/1 Process: Methane Steam Reforming, Western Europe Basis	157
Table 57	Cost of Production Estimate for: Synthesis Gas, H ₂ /CO= 1/1 Process: Methane Steam Reforming, China Coast Basis.....	158
Table 58	Cost of Production Estimate for: Synthesis Gas, H ₂ /CO= 1/1 Process: Methane Steam Reforming, Japan Basis.....	159
Table 59	Cost of Production Estimate for: Synthesis Gas, H ₂ /CO= 1/1 Process: Methane Steam Reforming, Southeast Asia Basis	160

Table 60	Cost of Production Estimate for: Formaldehyde (37 Weight Percent) Process: Silver Catalyst, Complete Conversion without Methanol Recycle, USGC Basis.....	161
Table 61	Cost of Production Estimate for: Formaldehyde (37 Weight Percent) Process: Silver Catalyst, Complete Conversion without Methanol Recycle, Western Europe Basis	162
Table 62	Cost of Production Estimate for: Formaldehyde (37 Weight Percent) Process: Silver Catalyst, Complete Conversion without Methanol Recycle, China Coast Basis.....	163
Table 63	Cost of Production Estimate for: Formaldehyde (37 Weight Percent) Process: Silver Catalyst, Complete Conversion without Methanol Recycle, Japan Basis.....	164
Table 64	Cost of Production Estimate for: Formaldehyde (37 Weight Percent) Process: Silver Catalyst, Complete Conversion without Methanol Recycle, Southeast Asia Basis.....	165



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:

Adam Chan, Managing Consultant

Phone: + 1-914-609-0326, e-mail: achan@NexantECA.com

Erica Hill, Client Services Coordinator, Subscriptions and Reports

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

EMEA:

Anna Ibbotson, Vice President, Sales and Marketing

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

Asia:

Chommanad Thammanayakatip, Managing Consultant

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

NexantECA Subscriptions and Reports provide clients with comprehensive analytics, forecasts and insights for the chemicals, polymers, energy and cleantech industries. Using a combination of business and technical expertise, with deep and broad understanding of markets, technologies and economics, NexantECA provides solutions that our clients have relied upon for over 50 years.

Copyright © 2000-2024. NexantECA (BVI) Limited. All rights reserved