

Biorenewable Insights Ethylene and Derivatives

Table of Contents

A Report by NexantThinking™

Published December 2014

www.nexantthinking.com

Section	Page
1 Executive Summary	1
1.1 OVERVIEW	1
1.2 TECHNOLOGIES	1
1.2.1 Ethylene	1
1.2.2 Bio-Ethylene Oxidation/EO Hydration	2
1.3 ECONOMICS	3
1.4 CAPACITY ANALYSIS	5
1.5 STRATEGIC IMPLICATIONS	7
1.5.1 Bio-Ethylene	8
1.5.2 Bio-Ethylene Oxide	9
1.5.3 Bio-Ethylene Glycol	9
2 Introduction	11
2.1 OVERVIEW	11
2.1.1 Polyethylene	12
2.1.2 Ethylene Oxide/Ethylene Glycol	13
2.1.3 Ethylene Dichloride, Vinyl Chloride Monomer, and Polyvinyl Chloride	13
2.1.4 Ethylbenzene/Styrene	13
2.1.5 Vinyl Acetate Monomer	14
2.1.6 Other Applications for Ethylene	14
2.2 BIO-BASED ETHYLENE	14
2.3 STRATEGIC AND BUSINESS CONSIDERATIONS	14
2.4 SPECIFICATIONS	15
2.5 STORAGE AND TRANSPORTATION	16
2.6 SCOPE OF WORK	17

3	Technology	18
3.1	BIO-ETHYLENE	18
3.1.1	Bio-Ethanol Dehydration	18
3.1.2	Oxidative Coupling of Methane (OCM)	24
3.2	BIO-ETHYLENE OXIDE (EO)	26
3.2.1	Bio-Ethylene Oxidation.....	26
3.3	BIO-ETHYLENE GLYCOL (MEG).....	29
3.3.1	Bio-Ethylene Oxidation/EO Hydration	29
3.3.2	Sugars to Ethylene Glycol.....	37
3.3.3	BIOMASS TO MEG VIA Dimethyl oxalate	39
3.3.4	Direct Conversion of Cellulose to MEG.....	40
3.4	OTHER MENTIONABLE TECHNOLOGIES	40
3.4.1	BP Hummingbird	40
3.4.2	Lummus Fluidized Bed.....	41
3.4.3	IFP/Axens/Total.....	41
3.5	CONVENTIONAL TECHNOLOGY FOR ETHYLENE PRODCUTION	43
3.5.1	Steam Cracking (Pyrolysis) of Hydrocarbons	43
3.5.2	Methanol to Olefins (via Methanol from Coal Syngas).....	48
4	Economics	53
4.1	ECONOMIC METHODOLOGY	53
4.1.1	Sources	53
4.1.2	Capital Cost Elements.....	53
4.1.3	Operating Cost Elements	57
4.2	COST OF PRODUCTION (COP) ESTIMATES	60
4.2.1	Bio-Ethylene	60
4.2.2	Bio-Ethylene Oxide.....	63
4.2.3	Bio-Ethylene Glycol	63
4.3	COMPARATIVE ECONOMICS.....	67
4.3.1	Regional Analysis.....	67
4.3.2	Process Analysis	71
4.4	SENSITIVITY ANALYSIS.....	76
4.4.1	Bio-Ethylene	76
4.4.2	Bio-Ethylene Oxide.....	80
4.4.3	Bio-Ethylene Glycol	84

5	Capacity Analysis	88
5.1	OVERVIEW	88
5.1.1	Types of Developments Considered	88
5.2	EXISTING COMMERCIAL CAPACITY	88
5.2.1	Braskem	88
5.2.2	Greencol Taiwan Corporation	88
5.2.3	India Glycols Limited	88
5.2.4	Solvay Indupa – Braskem	88
5.2.5	Reliance	89
5.2.6	Jilin Zhongxin Chemical Group	89
5.2.7	IHeyang Ethanol and Bio-Glycols Co.....	89
5.3	PROJECT CAPACITY ANALYSIS	89
5.3.1	Methodology.....	89
5.3.2	Dow/Mitsui.....	93
5.3.3	JBF	94
5.3.4	M&G Chemicals	95
5.3.5	BP.....	96
5.3.6	Versalis/Elevance.....	96
5.3.7	TOTAL/IFP	97
5.4	CONCLUSION	97
6	Implications for Conventional Technology	101
6.1	SCALE AND MARKET PENETRATION	101
6.1.1	Scale of Production	101
6.1.2	Market Penetration	101
6.1.3	Market Pull	103
6.2	PRICES AND MARGINS.....	104
6.2.1	Bio-Ethylene	104
6.2.2	Bio-Ethylene Oxide.....	105
6.2.3	Bio-Ethylene Glycol.....	106
7	Patent Analysis.....	107
7.1	OVERVIEW	107
7.2	GRANTED PATENTS	108
7.2.1	Global	108
7.2.2	North America	109
7.2.3	Europe.....	111

7.2.4	Asia.....	114
7.2.5	ROW.....	116
7.3	PATENT APPLICATIONS.....	117
7.3.1	Global.....	117
7.3.2	North America.....	119
7.3.3	Europe.....	122
7.3.4	Asia.....	125
7.3.5	ROW.....	128
8	References.....	130

Figure		Page
1.1	USGC Cost of Production Comparison by Product.....	3
1.2	Brazil Cost of Production Comparison by Product.....	4
1.3	Western Europe Cost of Production Comparison by Product.....	4
1.4	China Cost of Production Comparison by Product.....	5
2.1	Raw Material Feeds for Ethylene.....	11
3.1	Block Flow Diagram for Ethanol Production from Cane Juice or Molasses.....	18
3.2	Bio-Ethanol to Green Ethylene: Conceptual Process Flow.....	19
3.3	Braskem Ethanol Dehydration Process.....	21
3.4	Ethylene from Ethanol.....	23
3.5	Siluria's Simplified OCM Process Flow Diagram.....	25
3.6	Dow METEOR™ Glycol Reaction and Evaporation System.....	30
3.7	Glycol Reaction and Separation via SD Process.....	32
3.8	Shell OMEGA Process.....	35
3.9	Shell OMEGA Ethylene Glycol Section.....	36
3.10	Biomass to MEG Process.....	39
3.11	Simplified Mass Balance for Straw to MEG.....	40
3.12	Ethylene from Ethanol (Lummus).....	42
3.13	NGL Cracking (Cracking & Compression) Process Flow Diagram.....	45
3.14	NGL Cracking (Fractionation) Process Flow Diagram.....	46
4.1	USGC Cost of Production Comparison by Product.....	67
4.2	Brazil Cost of Production Comparison by Product.....	68
4.3	Western Europe Cost of Production Comparison by Product.....	69
4.4	China Cost of Production Comparison by Product.....	70

4.5	USGC Bio-Ethylene Feedstock Pricing Sensitivity	76
4.6	USGC Bio-Ethylene Investment Cost Sensitivity	77
4.7	USGC Bio-Ethylene Economy of Scale Sensitivity	78
4.8	USGC Bio-Ethylene ROCE Sensitivity	79
4.9	USGC Bio-EO Feedstock Pricing Sensitivity	80
4.10	USGC Bio-EO Investment Cost Sensitivity	81
4.11	USGC Bio-EO Economy of Scale Sensitivity	82
4.12	USGC Bio-EO ROCE Sensitivity	83
4.13	USGC Bio-MEG Feedstock Pricing Sensitivity	84
4.14	USGC Bio-MEG Investment Cost Sensitivity	85
4.15	USGC Bio-MEG Economy of Scale Sensitivity	86
4.16	USGC Bio-MEG ROCE Sensitivity	87
5.1	Risk Adjustment Methodology	93
6.1	Global Breakdown of Ethylene Production	102
6.2	Global Breakdown of MEG Production	102
7.1	Overall Patent Activity by Region	107
7.2	Granted Patents by Region	108
7.3	Granted Patents by Assignee	109
7.4	North American Granted Patents by Assignee	110
7.5	European Granted Patents by Assignee	112
7.6	Asian Granted Patents by Assignee	114
7.7	ROW Granted Patents	116
7.8	Patent Applications by Region	117
7.9	Patent Applications by Assignee	118
7.10	North American Patent Applications by Assignee	119
7.11	Europe Applications by Assignee	122
7.12	Asian Patent Applications by Assignee	125
7.13	ROW Patent Applications by Assignee	129

Table	Page
1.1 Announced Bioethylene Capacity	6
1.2 Adjusted Bioethylene Capacity.....	6
1.3 Bioethylene Glycol and Oxide Announced Capacity.....	7
1.4 Bioethylene Glycol and Oxide Adjusted Capacity.....	7
1.5 Margin and Returns of Bio-Ethylene Processes in all Regions.....	8
1.6 Margin and Returns of Bio-EO Processes in all Regions	9
1.7 Margin and Returns of Bio-MEG Processes in all Regions	10
2.1 Strategic/Business Considerations	15
2.3 Commercial Specification for Polymer Grade Ethylene	16
3.1 S2G Biochem Product Slate.....	38
4.1 Cost of Production Estimate for: Ethylene via Bio-Ethanol Dehydration	61
4.2 Cost of Production Estimate for: Bio-Ethylene via Siluria's OCM	62
4.3 Cost of Production Estimate for: Bio-EO via Bio-Ethylene Oxidation	64
4.4 Cost of Production Estimate for: Bio-MEG via Bio-Ethylene Oxidation/EO Hydration.....	65
4.5 Cost of Production Estimate for: Bio-MEG via Continuous Hydrogenation of Glucose	66
4.6 Bio-Ethanol Dehydration Comparative Economics	71
4.7 OCM Comparative Economics.....	72
4.8 Bio-Ethylene Oxidation Comparative Economics.....	73
4.9 Bio-Ethylene Oxidation/EO Hydration Comparative Economics.....	74
4.10 Continuous Hydrogenation of Glucose Comparative Economics	75
5.1 Project Scoring Methodology	89
5.2 Calculation Chart for Capacity Factor	90
5.3 Dow/Mitsui Project Scoring	93
5.4 JBF Chemicals Project Scoring.....	94
5.5 M&G Chemicals Project Scoring.....	95
5.6 BP Project Scoring	96
5.7 Versalis/Elevance Project Scoring	96
5.8 TOTAL/IFP Project Scoring.....	97
5.9 Announced Bioethylene Capacity	98
5.10 Adjusted Bioethylene Capacity.....	99
5.11 Bioethylene Glycol and Oxide Announced Capacity.....	99
5.12 Bioethylene Glycol and Oxide Adjusted Capacity	100
6.1 Margin and Returns of Bio-Ethylene Processes in all Regions.....	105
6.2 Margin and Returns of Bio-EO Processes in all Regions	105

6.3	Margin and Returns of Bio-MEG Processes in all Regions	106
7.1	Key Global Granted Patents.....	109
7.2	Key North American Granted Patents.....	110
7.3	North American Granted Patents	111
7.4	Key European Patents	112
7.5	European Granted Patents.....	112
7.6	Key Asian Patents	115
7.7	Asian Granted Patents	115
7.8	Rest of World Granted Patents	116
7.9	Key Global Patent Applications	118
7.10	Key North American Patent Applications	119
7.11	All North American Patent Applications	120
7.12	Key European Patents	122
7.13	Key European Patent Applications.....	123
7.14	Key Asian Patent Applications	125
7.15	Asian Patent Applications.....	126
7.16	Asian Patent Applications.....	129

NexantThinking™

Biorenewable Insights



www.nexantthinking.com

Nexant, Inc. (www.nexantthinking.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 .

Contact Details:

New York: Steven Slome

Phone: + 1-914-609-0379, e-mail: sslome@nexant.com

New York: Heidi Junker Coleman, Global Programs Support Manager

Phone: + 1-914-609-0381, e-mail: hcoleman@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. 2014. All Rights Reserved.