

Biorenewable Insights

Isobutanol

Table of Contents

A Report by NexantThinking™

Published August 2015

www.nexantthinking.com

Section		Page
1	Executive Summary	1
1.1	OVERVIEW	1
1.2	TECHNOLOGY	2
1.2.1	Gevo	2
1.2.2	Butamax™ Advanced Biofuels.....	3
1.2.3	Other Notable Technologies	4
1.3	ECONOMIC ANALYSIS	5
1.3.1	USGC	5
1.4	CAPACITY ANALYSIS.....	8
1.5	IMPLICATIONS ON CONVENTIONAL TECHNOLOGY.....	11
1.5.1	Scale and Market Penetration.....	11
1.5.2	Commercial Implications	11
1.5.3	Technical Implications	11
1.6	PATENT ANALYSIS.....	11
2	Introduction.....	13
2.1	OVERVIEW	13
2.2	BACKGROUND TO BUTANOLS	13
2.2.1	Bio-based Isobutanol.....	14
2.3	INDUSTRY DRIVERS AND END-USSES.....	15
2.4	SCOPE OF THE REPORT.....	15
3	Technology	17
3.1	OVERVIEW	17
3.2	CONVENTIONAL TECHNOLOGY.....	17
3.2.1	OXO Process	17

3.3	BIO-ISOBUTANOL TECHNOLOGIES	19
3.3.1	Gevo	19
3.3.2	Butamax™ Advanced Biofuels.....	25
3.3.3	Other Notable Technologies	35
4	Economic Analysis	37
4.1	ECONOMIC METHODOLOGY	37
4.1.1	Sources	37
4.1.2	Capital Cost Elements.....	37
4.1.3	Operating Cost Elements	41
4.2	ISOBUTANOL PRICING	44
4.3	COST OF PRODUCTION (COP) ESTIMATES	44
4.3.1	Gevo	45
4.3.2	Butamax™	45
4.4	COMPARATIVE ECONOMICS	50
4.4.1	Regional Analysis.....	50
4.4.2	Process Analysis	53
4.5	SENSITIVITY ANALYSIS.....	57
4.5.1	Feedstock Pricing.....	57
4.5.2	Investment Costs.....	58
4.5.3	Economy of Scale	58
4.5.4	ROCE	59
5	Capacity Analysis	60
5.1	OVERVIEW	60
5.2	EXISTING COMMERCIAL CAPACITY	60
5.3	PROJECT CAPACITY ANALYSIS.....	60
5.3.1	Methodology	60
5.4	ANNOUNCED PROJECTS	64
5.4.1	Gevo	64
5.4.2	Butamax™	68
5.5	CONCLUSION	69
6	Implications for Conventional Technology	72
6.1	SCALE AND MARKET PENETRATION	72
6.2	MARKET PULL AND END-USSES	73
6.2.1	End-Use Overview	73
6.2.2	Demand.....	74

6.2.3	Supply	75
6.2.4	Trade	77
6.3	PRICES AND MARGINS.....	78
6.4	STRATEGIC IMPLICATIONS	78
6.4.1	Commercial Implications	78
6.4.2	Technical Implications	79
7	Patent Analysis.....	80
7.1	OVERVIEW	80
7.2	GRANTED PATENTS	80
7.2.1	Global	80
7.2.2	North America	85
7.2.3	Europe.....	91
7.2.4	Asia.....	93
7.3	PATENT APPLICATIONS.....	95
7.3.1	Global	95
7.3.2	North America	99
7.3.3	Europe.....	109
7.3.4	Asia.....	110
8	References	117

Appendix		Page
A	COPs for Other Regions	A-1

Figure	Page
1.1 Isomers of Butanol	1
1.2 Historic USGC SPOT FOB Export Pricing	5
1.3 USGC Cost of Production Comparison.....	6
1.4 Brazil Cost of Production Comparison	7
1.5 Western Europe Cost of Production Comparison	7
1.6 China Cost of Production Comparison.....	8
1.7 Announced Isobutanol Capacity.....	9
1.8 Risk Adjusted Isobutanol Capacity.....	10
1.9 Overall Patent Activity by Region	12
2.1 Simplified Conventional Isobutanol Upstream Value Chain.....	13
2.2 Biobutanol Value Chain.....	16
3.1 Gevo Process for Isobutanol	20
3.2 Gevo Process Flow Diagram, U.S. Patent 8,304,588	21
3.3 Gevo's Pathway to Isobutanol()	24
3.4 Gevo Target Markets, TAM, and Partners	26
3.5 Gevo Target Markets and TAMs	27
3.6 Butamax™'s Timeline of Development	27
3.7 Butamax™'s Iso-butanol Pathway	30
3.8 Butamax™ Process Flow Diagram from U.S. 20120035398 A1	34
3.9 IEP's Methane Bioconversion Platform()	36
4.1 Historic USGC SPOT FOB Export Pricing	44
4.2 USGC Cost of Production Comparison.....	50
4.3 Brazil Cost of Production Comparison	51
4.4 Western Europe Cost of Production Comparison	52
4.5 China Cost of Production Comparison.....	53
4.6 USGC Bio-Isobutanol Feedstock Pricing Sensitivity	58
4.7 USGC Bio-Isobutanol Investment Cost Sensitivity.....	58
4.8 USGC Bio-Isobutanol Economy of Scale Sensitivity	59
4.9 USGC Bio-Isobutanol ROCE Sensitivity	59
5.1 Risk Adjustment Methodology	64
5.2 Announced Isobutanol Capacity.....	69
5.3 Risk Adjusted Isobutanol Capacity.....	71
6.1 Estimated Bio-Based Isobutanol Penetration.....	72
6.2 Global Isobutanol Consumption by Region.....	74

6.3	Global Isobutanol Capacity Share by Marketer in 2014.....	75
6.4	Global Isobutanol Capacity Additions	76
6.5	Global Isobutanol Capacity by Region	76
7.1	Overall Patent Activity by Region	80
7.2	Granted Patents by Region	81
7.3	Granted Patents by Assignee.....	81
7.4	North American Granted Patents by Assignee	86
7.5	European Granted Patents by Assignee.....	91
7.6	Asia Granted Patents by Assignee	94
7.7	Patent Applications by Region	96
7.8	Patent Applications by Assignee	96
7.9	North American Patent Applications by Assignee.....	99
7.10	European Patent Applications by Assignee	109
7.11	Asian Patent Applications by Assignee	111

Table	Page
1.1 Announced Bio-Isobutanol Capacity	9
1.2 Adjusted Bio-isobutanol Capacity	10
3.1 Oxo Alcohol Process Development.....	19
3.2 Butamax™'s Chemical Grade Isobutanol	35
4.1 Cost of Production Estimate for: Bio-Isobutanol via Gevo's GIFT Fermentation Process (USGC, First Quarter 2015)	46
4.2 Cost of Production Estimate for: Bio-Isobutanol via Gevo's Cellulosic Fermentation Process.....	47
4.3 Cost of Production Estimate for: Bio-Isobutanol via Butamax™'s Fermentation Process.....	48
4.4 Cost of Production Estimate for: Bio-Isobutanol via Butamax™'s Cellulosic Fermentation Process	49
4.5 Gevo's Fermentation Comparative Economics.....	54
4.6 Gevo's Cellulosic Comparative Economics.....	55
4.7 Butamax™'s Fermentation Comparative Economics	56
4.8 Butamax™'s Cellulosic Comparative Economics	57
5.1 Project Scoring Methodology	61
5.2 Calculation Chart for Capacity Factor	61
5.3 Gevo Malaysian Isobutanol Project Scoring	65
5.4 Gevo/Redfield Energy Project Scoring.....	66
5.5 Gevo/HIGHLANDS Envirofuels Project Scoring	67
5.6 Gevo/Porta Hnos Project Scoring	67
5.7 Gevo/Praj Industries Project Scoring	68
5.8 Butamax™/Highwater Ethanol Project Scoring.....	69
5.9 Announced Bio-Isobutanol Capacity	70
5.10 Adjusted Bio-isobutanol Capacity	70
6.1 Global Isobutanol Consumption by Region.....	74
6.2 Global Isobutanol Supply, Demand, and Trade	77
6.3 Margin and Returns of Bio-Butanol Processes in all Regions	78
7.1 Key Global Granted Patents.....	82
7.2 Key North American Granted Patents	87
7.3 United States Granted Patents.....	89
7.4 Key European Granted Patents	92
7.5 European Granted Patents.....	92
7.6 Asian Granted Patents	94
7.7 Key Global Patent Applications	97

7.8	Key North American Patent Applications	100
7.9	North American Patent Applications	102
7.10	Key European Patent Applications	109
7.11	European Patent Applications	110
7.12	Asian Patent Applications.....	111

NexantThinking™ Biorenewable Insights



Nexant, Inc. (www.nexanthing.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. 2015. All Rights Reserved.