

Biorenewable Insights

Ethanol: First and Next Generation

Table of Contents

A Report by NexantThinking™

Published December 2017

www.nexantthinking.com

Section	Page
1 Executive Summary	1
1.1 OVERVIEW	1
1.2 SECOND GENERATION ETHANOL TECHNOLOGY.....	1
1.3 ECONOMICS	3
1.4 CAPACITY ANALYSIS.....	3
1.5 IMPLICATIONS FOR CONVENTIONAL TECHNOLOGY	5
1.5.1 Global Market Overview	5
1.5.2 Strategic Implications	5
1.5.3 Prices and Margins.....	6
2 Introduction.....	7
2.1 OVERVIEW	7
2.1.1 Drivers for Commercialization of Next Generation Ethanol	7
2.2 BACKGROUND TO ETHANOL PRODUCTION	8
2.2.1 Fossil Ethanol.....	8
2.2.2 Fermentative Bioethanol	9
2.2.3 Bio-refining and Cellulosic Sugars	13
2.2.4 Non-Fermentative Bioethanol Production	17
3 Technology	18
3.1 FIRST-GENERATION ETHANOL	18
3.1.1 Corn	18

3.1.2	Sugarcane	33
3.1.3	Minor Feedstocks	37
3.2	NEXT GERNATION ETHANOL	38
3.2.1	Hydrolysis and Fermentation	38
3.2.2	Syngas Fermentation	57
3.2.3	Gasification and Syngas Reforming	65
4	Economics	70
4.1	METHODOLOGY	70
4.1.1	Capital Cost Elements	70
4.1.2	Operating Cost Elements	73
4.2	FEEDSTOCKS SUPPLY AND LOGISTICS	76
4.2.1	Fermentation Feedstocks	76
4.2.2	Hydrolysis Feedstock	76
4.2.3	Syngas Fermentation Feedstock	77
4.2.4	Further Reading on Feedstocks	77
4.3	COST OF PRODUCTION (COP) ESTIMATES	77
4.3.1	Dry Milling of Corn	77
4.3.2	Sugarcane Milling	79
4.3.3	Beta Renewables – PROESA Technology	79
4.3.4	LanzaTech – Syngas Fermentation	79
4.4	COMPARATIVE ECONOMICS	83
4.4.1	Comparison by Region	83
4.4.2	Comparison by Process	87
4.5	Sensitivity Analysis	89
4.5.1	Primary Feedstock Sensitivity	89
4.5.2	Utility Sensitivity	90
4.5.3	CAPEX Sensitivity	91
4.5.4	Economy of Scale Sensitivity	91
5	Capacity Analysis	93
5.1	OVERVIEW	93
5.2	METHODOLOGY	93
5.2.1	Types of Developments Considered	96
5.3	EXISTING CAPACITY	96
5.3.1	Existing First-Generation Ethanol Industry	96
5.3.2	Existing Second Generation Ethanol Industry	103

5.4	ANNOUNCED PROJECTS	106
5.4.1	California Ethanol and Power (CE+P).....	106
5.4.2	Inbicon	107
5.4.3	IGPC Ethanol	108
5.4.4	Elite Octane	108
5.4.5	AI-Corn Clean Fuel.....	109
5.4.6	KAAPA Ethanol Ravenna.....	109
5.4.7	Western New York Energy.....	110
5.4.8	Ring-Neck Energy	111
5.4.9	Beta Renewables	112
5.4.10	LanzaTech.....	114
5.4.11	Chempolis	116
5.4.12	Suomen Bioetanol	117
5.4.13	Greenfield Global	117
5.4.14	Woodland Biofuels	118
5.5	RISK ADJUSTED CAPACITIES	119
6	Implications for Conventional Technology	120
6.1	REGIONAL MARKET ANALYSIS	120
6.1.1	Global Ethanol Overview.....	120
6.1.2	United States Ethanol Market	121
6.1.3	Brazil Ethanol Market	123
6.1.4	China Ethanol Market.....	123
6.2	STRATEGIC IMPLICATIONS	124
6.2.1	Market Implications	124
6.2.2	Technical Implications	125
6.3	PRICES AND MARGINS.....	126
6.3.1	Prices	126
6.3.2	Margins.....	127

Figure	Page
1.1 Ethanol Regional Cost Competitiveness Estimates	3
1.2 Global Second Generation Ethanol Capacity, 2016	4
1.2 Global Ethanol Production by Region, 2016	5
2.1 Ribbon Representation of a Cellulase Enzyme.....	15
3.1 Global Corn Production, 2017 Estimate.....	18
3.2 Wet Milling versus Dry Milling Process Flow.....	19
3.3 Corn Milling and Hydrolysis	21
3.4 Saccharification	22
3.5 Fermentation	23
3.6 Ethanol Beer Still.....	24
3.7 Ethanol Rectifier and Dehydration	25
3.8 DDGS Drying.....	26
3.9 Flow Diagram of Cane Milling Process for Ethanol and Sugar Production.....	35
3.10 Block Flow Diagram of Ethanol Production from Sugarcane	36
3.11 Beta Renewables PROESA Technology	39
3.12 Inbicon's IBUS Process for Biomass to Ethanol	43
3.13 Iogen's Cellulose Ethanol Process.....	45
3.14 SUNLIQUID® Process of Clariant.....	48
3.15 Chempolis' FormicoBio™ Process	51
3.16 DuPont Cellulosic Ethanol Process Flow	53
3.17 LanzaTech Block Flow Diagram	58
3.18 LanzaTech Reactor System.....	60
3.19 Enerkem Technology	65
3.20 CPR™ Technology.....	68
4.1 United States Cost of Production Comparison – Ethanol	83
4.2 Brazil Cost of Production Comparison – Ethanol	84
4.3 China Cost of Production Comparison – Ethanol.....	85
4.4 Overall Cost of Production Comparison – By Region	86
4.5 Beta Renewables' PROESA Technology Cost of Production Comparison – Ethanol	87
4.6 LanzaTech Cost of Production Comparison – Ethanol	88
4.7 Overall Cost of Production Comparison – By Process	89
4.8 United States Primary Feedstock Sensitivity	90
4.9 United States Ethanol Utility Sensitivity	90
4.10 United States Ethanol CAPEX Sensitivity	91

4.11	United States Ethanol Economy of Scale Sensitivity	92
5.1	Global Ethanol Demand by End Use, 2017 Estimate	97
5.2	Global Ethanol Production by Region	97
5.3	Global Second Generation Ethanol Capacity, 2016	104
6.1	Global Ethanol Production by Region, 2016	120
6.2	United States Ethanol Capacity by Feedstock, 2016	121
6.3	United States Ethanol Production	122
6.4	United States Ethanol Production by State, 2016	122
6.5	Brazil Ethanol Production by Feedstock, 2016	123
6.3	Ethanol Cost of Production Summary versus Market Price	128

Table	Page
1.1 Second Generation Ethanol Developers	2
1.2 Announced Ethanol Capacity Additions	4
3.1 Beta Renewables Recent Key Patent Activity.....	41
3.2 Inbicon Recent Key Patent Activity	43
3.3 Iogen Recent Key Patent Activity	46
3.4 Clariant Recent Key Patent Activity	49
3.5 DuPont Recent Key Patent Activity	53
3.6 POET-DSM Key Patent Activity	57
3.7 LanzaTech Key Patent Activity.....	62
3.8 Enerkem Key Patent Activity	67
3.9 Woodlands Biofuels Key Patent Activity	69
4.1 Cost of Production Estimate for: Ethanol via Dry Milling of Corn (United States, 2017)	78
4.2 Cost of Production Estimate for: Ethanol via Sugarcane Fermentation (Brazil, 2017)	80
4.3 Cost of Production Estimate for: Ethanol via Beta Renewables' PROESA Technology (United States, 2017)	81
4.4 Cost of Production Estimate for: Ethanol via LanzaTech's Syngas Fermentation (United States, 2017)	82
4.5 United States Cost of Production Comparison – Ethanol	83
4.6 Brazil Cost of Production Comparison – Ethanol	84
4.7 China Cost of Production Comparison – Ethanol.....	85
4.8 Beta Renewables' PROESA Technology Cost of Production Comparison – Ethanol	87
4.9 LanzaTech Cost of Production Comparison – Ethanol	88
5.1 Project Scoring Methodology	93
5.2 North America First Generation Ethanol Capacity, 2017 Estimate	98
5.3 Existing Global Cellulosic Ethanol Capacity.....	104
5.4 Announced Ethanol Capacity Additions	106
5.4 California Ethanol and Power Project Scoring	107
5.5 Inbicon Maabjerg, Denmark Project Scoring.....	107
5.6 IGPC Ethanol Expansion Project Scoring	108
5.7 Elite Octane Project Scoring	109
5.8 AI-Corn Clean Fuel Expansion Project Scoring	109
5.9 KAAPA Ethanol Ravenna Project Scoring	110
5.10 Western New York Energy Project Scoring	111
5.11 Ring-Neck Energy Project Scoring.....	111

5.12 Beta Renewables Project Alpha Project Scoring	112
5.13 M&G Chemical's Fuyang Bioproject Project Scoring	113
5.14 Biochemtex's Energochemica Project Scoring	114
5.15 Shougang LanzaTech Project Score	114
5.15 IndianOil Project Score.....	115
5.16 Aemetis Project Score.....	115
5.17 ArcelorMittal Project Score.....	116
5.18 Chempolis and NRL Project Scoring.....	116
5.21 Adjusted Ethanol Capacity Additions	119
6.1 Types of RINs.....	126

NexantThinking™ Biorenewable Insights



Nexant, Inc. (www.nexanthinking.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

Erica Hill, Client Services Coordinator, E&CA-Products
Phone: + 1-914-609-0386, e-mail: ehill@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. 2017. All Rights Reserved.