

**TECHNOLOGY & COSTS****Biorenewable Insights****Biocoal and Biocrude**

## Table of Contents

A Report by **NexantECA, Inc.**

Published Date: November 2020

[www.nexanteca.com/subscriptions-and-reports](http://www.nexanteca.com/subscriptions-and-reports)**Contents**

1	Executive Summary .....	1
1.1	Overview.....	1
1.2	Introduction.....	1
1.3	Technology .....	1
1.4	Economics .....	2
1.4.1	Biocoal.....	2
1.4.2	Biocrude .....	3
1.5	Capacity Analysis .....	5
1.6	Impact on the Conventional Industry.....	7
1.6.1	Crude Quality .....	7
1.6.2	Coprocessing .....	7
2	Introduction .....	8
2.1	Introduction: Biocoal and Biocrude .....	8
2.2	Combustion Processes: Pyrolysis, Torrefaction and Hydrothermal Carbonization HTN .....	9
2.2.1	Pyrolysis .....	9
2.2.2	Torrefaction .....	9
2.2.3	Hydrothermal Carbonization (HTC).....	10
2.2.4	Hydrothermal Liquefaction .....	11
2.3	Uses for Biocoal and Biocrude .....	11
2.3.1	Biocoal.....	11
2.3.2	Uses of Biocrude .....	11
2.4	Feeds.....	11
2.4.1	Biomass Residues and Waste .....	12
2.5	Biomass Feedstocks and Availability (Global/Focus U.S.) .....	15
2.5.1	Agricultural Wastes and Other Biomass .....	16
2.6	Uses of Biocoal .....	27
2.6.1	Introduction.....	27
2.6.2	Power Generation Uses, Cofiring Coal .....	27

2.6.3	Industrial Uses.....	27
2.7	Carbon Neutrality. Is Biocarbon Carbon Neutral?.....	30
3	Technology .....	31
3.1	Biocoal Processes/Manufacturers.....	31
3.1.1	Torrefaction Process .....	31
3.1.2	Biomass Pyrolysis Process .....	41
3.1.3	Hydrothermal Carbonization .....	50
3.1.4	Hydrothermal Liquefaction (HTL) .....	52
3.1.5	U.S. Incentives for Torrefaction/Related Processes .....	55
3.2	Biocoal Companies .....	56
3.2.1	BTG Biomass Technology (Torrefaction, Pyrolysis) .....	56
3.2.2	Consortium for Advanced Wood-to-Energy Solutions Strategy .....	59
3.2.3	Agritech (ATP) .....	61
3.2.4	Restoration Fuels/Oregon .....	62
3.2.5	Airex Energy - Carbon FX™ .....	63
3.2.6	American Biocarbon and TSI .....	64
3.2.7	Global Bio Coal Energy (GBCE) Wyssmont Turbodrier Technology .....	67
3.2.8	Stork (Fluor)/Clean Electricity Generation (CEG) with Biocoal UK/Estonia .....	68
3.2.9	CHAR Technologies (Partnership with ArcelorMittal) .....	69
3.2.10	Clean Electricity Generation (CEG) (UK) .....	71
3.2.11	Ingelia Spain.....	72
3.2.12	Industry Source/Vega Biofuels.....	74
3.2.13	Airex/CarbonFX –Biocoal Pellets-Canada .....	75
3.2.14	Bioendev (Umea/Daiwa Energy) .....	77
3.2.15	Envigas (Sweden) .....	79
3.2.16	HM3 Energy .....	80
3.2.17	River Basin Energy/Biomass Secure Power (BSP) Inc. .....	81
3.2.18	Diacarbon Energy.....	82
3.2.19	Stramproy (Netherlands) Torrefaction to Biocoal-Steenwijk Project (CANCELLED) .....	83
3.2.20	New Biomass Energy/Solvay (CANCELLED) .....	83
3.3	Biocrude Offtakers.....	84
3.3.1	Fortum/Valmet .....	84
3.3.2	Ensyn (UOP Technology) .....	87
3.3.3	Pyrocell/Empyro Projects (Technip/BTG-BTL Technology) .....	90
3.3.4	Ongoing Biocrude Research/Demo Plants .....	93
4	Economics of Biocoal/Biocrude .....	100
4.1	Economic Analysis Methodology .....	100
4.1.1	Sources .....	100
4.1.2	Costing Basis .....	100
4.1.3	Capital Cost Elements.....	101
4.1.4	Operating Cost Elements .....	104

4.2	Competitive Economics.....	108
4.2.1	Biocoal.....	108
4.2.2	Biocrude .....	111
4.3	Cost of Production Models .....	115
4.3.1	Biocoal.....	115
4.3.2	Biocrude .....	119
5	Capacity Analysis .....	131
5.1	Announced Capacities .....	131
5.2	Project Analysis.....	132
5.2.1	BTG Biomass Technology .....	132
5.2.2	Agritech Producers.....	132
5.2.3	Restoration Fuels .....	132
5.2.4	Airex Energy-Carbon FX .....	133
5.2.5	Global Biocoal Energy.....	133
5.2.6	Stork/CEG/Poiry .....	134
5.2.7	Char Technologies .....	134
5.2.8	CEG .....	134
5.2.9	Ingella Spain.....	135
5.2.10	Industry Source/Vega.....	135
5.2.11	HM3 Energy .....	135
5.2.12	Bioendev .....	136
5.2.13	Envigas.....	136
5.2.14	Riverbasin Energy .....	136
5.2.15	Boreal Energy.....	136
5.2.16	Fortum/Valmet.....	137
5.2.17	Ensyn .....	137
5.2.18	Pyrocell/Empyro .....	138
5.3	Adjusted Capacity Listing .....	138
6	Impact on the Conventional Industry.....	140
6.1	Biocrude Quality Considerations .....	140
6.1.1	Biocrude Chemical/Physical Properties .....	140
6.1.2	Refinery Meaningful Metrics.....	141
6.1.3	Final Product Quality Considerations.....	142
6.2	Coprocessing Biofeeds in Refineries .....	142
6.2.1	Bioderived Fuels.....	142
6.2.2	Coprocessing basics .....	146
6.2.3	Refinery Insertion Points .....	147
6.2.4	Main Processing Units for Biofeeds/Blends .....	148
6.2.5	Relevant Pilot Plant Trials .....	149
6.2.6	Coprocessing Issues .....	151
6.2.7	Refineries That Could Process Biofeeds/Biocrudes .....	152
6.2.8	Coprocessing/Blending (Final Products) .....	152

## Figures

Figure 1	Competitive Economics for Biocoal .....	2
Figure 2	Catalytic Pyrolysis Cost of Production Comparison .....	3
Figure 3	Pyrolysis Cost of Production Comparison .....	4
Figure 4	Hydrothermal Liquefaction Cost of Production Comparison .....	4
Figure 5	Development of Biofuel Generation.....	12
Figure 6	EPA Food Waste Recovery Hierarchy .....	14
Figure 7	Map of Annual Switchgrass Yields, as of 2009 .....	17
Figure 8	Hybrid Poplar Yield versus Tree Age .....	19
Figure 9	U.S. Regional Production of Corn Stover, County-level.....	20
Figure 10	Geographic Distribution of Biomass in China .....	21
Figure 11	Brazil and India Sugarcane Production .....	25
Figure 12	NCC Asphalt Production Site .....	29
Figure 13	Torrefaction Process Schematic.....	33
Figure 14	Torrefaction Reactor Types .....	34
Figure 15	Rotary Drum Reactors .....	36
Figure 16	Belt Dryer.....	37
Figure 17	Percent Yield of the End Products during the Pyrolysis of Biomass .....	43
Figure 18	Representation of the Reaction Paths for Wood Pyrolysis .....	47
Figure 19	Commercial Fast Pyrolysis Bio-Oil Production.....	49
Figure 20	Hydrothermal Carbonization (HTC) Process.....	51
Figure 21	Reaction Scheme of Hydrothermal Liquefaction (HTL).....	53
Figure 22	Schematic of Steeper Energy's Hydrofaction® .....	54
Figure 23	Steeper Pilot Plant in Aalborg, Denmark .....	55
Figure 24	SGF Tofte, Norway Plant and Hydrofaction® Reactor .....	55
Figure 25	Torrefaction Pilot Plants (BTG).....	56
Figure 26	BTG Reactor Schematic .....	57
Figure 27	BTG's Product .....	58
Figure 28	Process Flow Diagram of HTL.....	60
Figure 29	Agritech's Torrefaction Process.....	62
Figure 30	American Biocarbon Process Schematic .....	66
Figure 31	Characteristics of the Biomass Separation Unit (BSU) and Dryer/Torrefaction and Densification Processes .....	66
Figure 32	Ingelia's Projects and Growth .....	74
Figure 33	Carbon FX Torrefaction Process .....	76
Figure 34	Integrated Pyrolysis Oil Production Technology.....	86
Figure 35	Fortum CHP Plant.....	87
Figure 36	Envergent RTP Process Flow Scheme .....	89
Figure 37	View of Setra's Kastet Sawmill - Gävle, Sweden (Feedstock for Biooil Production).....	90
Figure 38	The Empyro Woody Biomass Pyrolysis Plant in Hengelo, the Netherlands .....	92
Figure 39	BioLiq KIT Process .....	97
Figure 40	3-inch Biocarbon Briquette made at Biovalco's Biomass Densification Facility .....	98

Figure 41	Average Annual Prices of Coal Delivered to End Users 2009-2019 .....	109
Figure 42	Competitive Economics for Biocoal .....	110
Figure 43	Catalytic Pyrolysis Cost of Production Comparison .....	111
Figure 44	Pyrolysis Cost of Production Comparison .....	112
Figure 45	Hydrothermal Liquefaction Cost of Production Comparison .....	112
Figure 46	USGC Biocrude Cost of Production Comparison .....	113
Figure 47	China Biocrude Cost of Production Comparison .....	113
Figure 48	Brazil Biocrude Cost of Production Comparison .....	114
Figure 49	Western Europe Biocrude Cost of Production Comparison .....	114
Figure 50	Possible Biocrude/Biointermediates Insertion Points in Refineries .....	147

## Tables

Table 1	Global Biocrude and Biocoal Projects Announced Capacity Listing .....	5
Table 2	Global Biocrude and Biocoal Projects Adjusted Capacity Listing .....	6
Table 3	Selected Biomass Feedstock for Torrefaction, Pyrolysis, etc. ....	16
Table 4	SWOT Analysis of Grasses as a Biomass Feedstock.....	18
Table 5	Composition of Wheat Straw .....	22
Table 6	Biomass Pyrolysis Results Using a Conical Spouted Bed Reactor .....	48
Table 7	BTG: Properties from Typical Wood derived Pyrolysis Oil .....	59
Table 8	Ingelia Biocoal Characteristics .....	74
Table 9	Airex Biocoal Pellets compared to Industrial (Wood) Pellets and Coal.....	77
Table 10	RTP Yields from Woody Feedstocks.....	88
Table 11	BioCoal via Torrefaction Cost of Production Estimate, USGC .....	115
Table 12	BioCoal via Torrefaction Cost of Production Estimate, China .....	116
Table 13	BioCoal via Torrefaction Cost of Production Estimate, Brazil .....	117
Table 14	BioCoal via Torrefaction Cost of Production Estimate, Western Europe .....	118
Table 15	BioCrude via Catalytic Pyrolysis Cost of Production Estimate, USGC .....	119
Table 16	BioCrude via Catalytic Pyrolysis Cost of Production Estimate, China .....	120
Table 17	BioCrude via Catalytic Pyrolysis Cost of Production Estimate, Brazil.....	121
Table 18	BioCrude via Catalytic Pyrolysis Cost of Production Estimate, Western Europe .....	122
Table 19	BioCrude via Pyrolysis Cost of Production Estimate, USGC .....	123
Table 20	BioCrude via Pyrolysis Cost of Production Estimate, China .....	124
Table 21	BioCrude via Pyrolysis Cost of Production Estimate, Brazil.....	125
Table 22	BioCrude via Pyrolysis Cost of Production Estimate, Western Europe.....	126
Table 23	BioCrude via Hydrothermal Liquefaction Cost of Production Estimate, USGC.....	127
Table 24	BioCrude via Hydrothermal Liquefaction Cost of Production Estimate, China.....	128
Table 25	BioCrude via Hydrothermal Liquefaction Cost of Production Estimate, Brazil .....	129
Table 26	BioCrude via Hydrothermal Liquefaction Cost of Production Estimate, Western Europe .....	130
Table 27	Global Biocrude and Biocoal Projects Announced Capacity Listing .....	131
Table 28	BTG Biomass Technology.....	132
Table 29	Agritech Producers .....	132
Table 30	Restoration Fuels.....	132
Table 31	Airex Energy-Carbon FX .....	133
Table 32	Airex-Carbon FX II .....	133
Table 33	Global Biocoal Energy .....	133
Table 34	Stork/CEG/Pöyry .....	134
Table 35	Char Technologies .....	134
Table 36	CEG .....	134
Table 37	Ingella Spain .....	135
Table 38	Industry Source/Vega .....	135
Table 39	HM3 Energy.....	135
Table 40	Bioendev .....	136

Table 41	Envigas .....	136
Table 42	Riverbasin Energy .....	136
Table 43	Boreal Energy .....	137
Table 44	Fortum/Valmet .....	137
Table 45	Ensyn .....	137
Table 46	Ensyn II .....	137
Table 47	Pyrocell/Empyro .....	138
Table 48	Pyrocell/Empyro II .....	138
Table 49	Global Biocrude and Biocoal Projects Adjusted Capacity Listing .....	139
Table 50	Comparison of Biocrude Properties with Conventional Fuels .....	141
Table 51	EPA December 2019 Final Volume Requirements .....	145
Table 52	Biointermediates Characteristics and Refinery Requirements .....	153
Table 53	Comparison of FCC and Hydroprocessing as Refinery Co-processing Platforms for Bio-oils .....	155



## TECHNOLOGY & COSTS

# Biorenewable Insights

The NexantECA Subscriptions' Biorenewable Insights program is recognized globally as the industry standard source for information relevant to the chemical process and refining industries. Biorenewable Insights 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@nexant.com](mailto:mcesar@nexant.com)

Erica Hill, Client Services Coordinator, E&CA-Products  
Phone: + 1-914-609-0386, e-mail: [ehill@nexant.com](mailto:ehill@nexant.com)

#### EMEA:

Anna Ibbotson, Director, NexantECA Subscriptions  
Phone: +44-207-950-1528, [aibbotson@nexant.com](mailto:aibbotson@nexant.com)

#### Asia:

Chommanad Thammanayakatip, Managing Consultant, Energy & Chemicals Advisory  
Phone: +66-2793-4606, email: [chommanadt@nexant.com](mailto:chommanadt@nexant.com)

**NexantECA** ([www.nexantECA.com](http://www.nexantECA.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 NexantECA. 2020. All Rights Reserved.