

Industrial Enzymes — Cellulase Production for Bioethanol

PEP Review 2025-03

Tanushri Sood, Senior Research Specialist, Process Economics Program

To learn more or to request a demo, visit www.spglobal.com/commodityinsights.

Table of contents

Abstract	7
1 Introduction	8
2 Summary	9
Commercial and technical aspects	9
Operating conditions	11
Process economics	12
Environmental footprint	13
Economics calculation modules for non-US regions	13
Conclusion	13
3 Industry status and technical review	14
Cellulase enzymes industry	14
Impact of cellulase enzyme cost on bioethanol production	15
Commercial cellulases for bioethanol production	17
Role of cellulase enzymes in bioethanol production	18
Impact of process parameters on enzyme requirement	19
Lignocellulosic biomass source	20
Lignocellulosic biomass structure	20
Corn stover as lignocellulosic biomass feedstock	23
Cellulase enzyme complex	24
Mechanism of action of the cellulase enzyme complex	25
Other enzymes involved in lignocellulose digestion	26
Cellulase-producing microorganisms	27
Stages of cellulase enzyme production by microorganisms	28
Approaches for cellulase enzyme production	28
Off-site mode:	28
On-site mode	28
Integrated mode	28
Consolidated mode	29
Factors influencing cellulase enzyme production	29
Pretreatment of biomass feedstock	29
Fermentation methodology	33
Submerged fermentation (SmF)	33
Solid-state fermentation (SsF)	33
Studies on cellulase enzyme production	34
4 Process description and economics	37
Plant design capacity	37
Process description	40
Considerations	40
Section 100: Feedstock handling and storage (A100)	40
Section 200: Feedstock pretreatment (A200)	40

Section 300: Cellulase enzyme production (A300)	41
Section 400: Bioethanol production (A400)	42
Process discussion	47
Materials of construction	48
Cost estimates	49
Fixed capital costs	49
Capital cost for the pretreatment of corn stover feedstock	49
Capital cost for cellulase enzyme production	50
Capital cost for integrated bioethanol production using pretreated corn stover and cellulase enzyme	50
Production costs	53
Production cost for the pretreatment of corn stover feedstock	53
Production cost for cellulase enzyme production	54
Production cost for integrated bioethanol production using pretreated corn stover and cellulase enzyme	54
Contribution of cellulase enzyme cost in bioethanol cost	54
Environmental footprint	57
Appendix A — Design and cost basis	58
Design conditions	59
Cost basis	59
Cost basis	59
Capital investment	59
Project construction timing	60
Available utilities	60
Production costs	61
Effect of operating level on production costs	61
Appendix B — Cited references	62
Appendix C — Process flow diagrams	65

Tables

Table 2.1 Process summary for the production of cellulase enzymes for bioethanol	11
Table 2.2 Production of cellulase enzyme for bioethanol using pretreated corn stover for an integrated plant — Total capital investment	12
Table 2.3 Economics of the production of pretreated corn stover	12
Table 2.4 Economics of the production of cellulase enzyme	12
Table 2.5 Economics of the production of integrated bioethanol using pretreated corn stover and cellulase enzyme	13
Table 2.6 Carbon and water footprint	13
Table 3.1 Some commercial cellulase enzyme producers	18
Table 3.2 Lignocellulose composition of some biomass samples	21
Table 3.3 Composition range of corn stover	24
Table 3.4 Different categories of pretreatment for lignocellulosic biomass	31
Table 3.5 Fermentation conditions of different SmF and SsF studies	35
Table 3.6 Studies on cellulase enzyme production	36
Table 4.1 Production of cellulase enzymes for bioethanol	39
Table 4.2 Pretreatment reactions	41
Table 4.3 Seed and cellulase fermenter reactions	42
Table 4.4 Production of cellulase enzymes for bioethanol — Stream flows	43
Table 4.5 Production of cellulase enzymes for bioethanol — Major equipment	48
Table 4.6 Production of cellulase enzymes for bioethanol — Utilities summary	49
Table 4.7 Production of pretreated corn stover feedstock — Total capital investment	50

Table 4.8 Production of cellulase enzyme — Total capital investment	51
Table 4.9 Production of integrated bioethanol using pretreated corn stover and cellulase enzyme — Total capital investment	52
Table 4.10 Production of integrated bioethanol using pretreated corn stover and cellulase enzyme — Total capital investment by section	53
Table 4.11a Production of pretreated corn stover feedstock — Variable costs	54
Table 4.11b Production of pretreated corn stover feedstock — Production costs	55
Table 4.12a Production of cellulase enzyme — Variable costs	55
Table 4.12b Production of cellulase enzyme — Production costs	56
Table 4.13a Production of integrated bioethanol using pretreated corn stover and cellulase enzyme — Variable costs	56
Table 4.13b Production of integrated bioethanol using pretreated corn stover and cellulase enzyme — Production costs	57
Table 4.14 Production of cellulase enzyme — Carbon and water footprint	57

Figures

Figure 2.1 Raw materials and utilities consumption to produce cellulase enzyme for bioethanol	10
Figure 3.1 Contribution of enzyme loading to bioethanol selling price	17
Figure 3.2 Conventional biochemical process for biomass-to-bioethanol production using the cellulase enzyme complex	19
Figure 3.3 Structure of lignocellulose	23
Figure 3.4 Action of the cellulase enzyme complex on cellulose	25
Figure 3.5 Strategies for cellulase enzyme production	30
Figure 4.1 BFD for the production of cellulase enzyme from corn stover	38
Figure 4.2 Raw materials and utilities consumption to produce integrated bioethanol using pretreated corn stover and cellulase enzyme	43

Appendix C Figures

Figure C1 Cellulase production for bioethanol	66
---	----

Glossary

°C	Degrees Celsius
°F	Degrees Fahrenheit
¢/kWh	Cents per kilowatt-hour
¢/lb	Cents per pound
¢/Mgal	Cents per thousand gallons
\$/gal	Dollars per gallon
\$/h	Dollars per hour
\$/kg	Dollars per kilogram
\$/Mgal	Dollars per thousand gallons
\$/t	Dollars per metric ton
μmol	Micromole
AFEX	Ammonia fiber explosion
ARP	Ammonia recycled percolation
atm	Atmosphere(s)
BFD	Block flow diagram
BGL	β-glucosidase
bhp	Brake horsepower
BLI	Battery limits investment
Btu	British thermal units
CAGR	Compound annual growth rate
CAZymes	Carbohydrate-active enzymes
CBD	Carbohydrate-binding domain
CBH	Cellobiohydrolase
CBM	Carbohydrate-binding module
CCR	Carbon catabolite repression
CD	Catalytic domain
CMCase	Carbomethoxycellulose
C/N	Carbon-to-nitrogen ratio
CSL	Corn steep liquor
Da	Daltons
DP	Degree of polymerization
EC	Enzyme commission
EG	Endoglucanase
FOB	Free/freight on board
FPU	Filter paper unit
ft	Feet
g	Gram(s)
G&A	General and administrative
gal	Gallon(s)
g/L	Grams per liter
GH	Glycosyl hydrolase
GHG	Greenhouse gas
gpm	Gallons per minute
Gt	Billion metric tons
h	Hour(s)
HMF	Hydroxymethyl furfural
hp	Horsepower
ISBL	Inside battery limits
kg	Kilogram(s)
kg/h	Kilograms per hour
kJ	Kilojoule(s)
KTPA	Kilotons per annum
kW	Kilowatt(s)
kWh	Kilowatt-hour(s)
lb	Pound(s)
lb/h	Pounds per hour
lb/lb	Pounds per pound
L-h	Liter-hour(s)
MESP	Minimum ethanol selling price
mg	Milligrams

Mgal	Thousand gallons
Mlb	Thousand pounds
mm	Millimeter(s)
mM	Millimolar
MMBtu/h	Million British thermal units per hour
MMgal/y	Million gallons per year
MMlb/y	Million pounds per year
MMt	Million metric tons
MMt/y	Million metric tons per year
Mol. wt.	Molecular weight
MPa	Megapascal(s)
N	Normality
NREL	National Renewable Energy Laboratory
PEP	Process Economics Program
PFD	Process flow diagram
pH	Potential of hydrogen
psi	Pounds per square inch
psia	Pounds per square inch absolute
psig	Pounds per square inch gauge
R&D	Research and development
ROI	Return on investment
rpm	Revolutions per minute
SAA	Soaking in aqueous ammonia
scf	Standard cubic feet
SHF	Separate hydrolysis and fermentation
SmF	Submerged fermentation
SPORL	Sulfite pretreatment to overcome recalcitrance of lignocellulose
sq ft	Square feet
SS	Stainless steel
SSCF	Simultaneous saccharification and co-fermentation
SsF	Solid-state fermentation
SSF	Simultaneous saccharification and fermentation
t	Metric ton(s)
t/h	Metric tons per hour
t/y	Metric tons per year
TFC	Total fixed capital
USDA	United States Department of Agriculture
USGC	United States Gulf Coast
vol%	Volume percent
v/w	Volume by weight
W	Watt(s)
wt%	Weight percent
w/w	Weight for weight
y	Year

Abstract

A large barrier to achieving the goal of producing low-cost biofuels is the high cost of enzymatic hydrolysis treatment — a crucial step in turning biomass into liquid biofuels. Several enzymatic strategies have been employed to degrade the cellulosic polysaccharides present in plant-based biomass into sugars for further conversion into biofuels. Bioethanol is produced by releasing the sugars from biomass and then fermenting those sugars into alcohol. Breaking down lignocellulose-based biomass, such as crop or forestry residues, is a difficult task. This requires pretreatment with dilute acid or other techniques to make the cellulose vulnerable to enzymatic hydrolysis, which involves using cellulase enzymes to convert the cellulose into glucose and other C₅-C₆ sugars.

Cellulosic ethanol (bioethanol) prices depend heavily (30%-70%) on the cost of the cellulase enzymes used to break down the biomass into fermentable sugars. While the relatively high cost of cellulase enzyme complex remains a major barrier to their commercial application, it is possible to reduce cellulase enzyme-related costs by integrating enzyme production with bioethanol production. Therefore, having the cellulase enzyme production on-site, or at the bioethanol production plant, and using the same biomass as feedstock for both processes, it is possible to make cellulosic ethanol economically viable.

This review sheds light on the industry status, process chemistry and technology landscape for cellulase enzyme production for bioethanol, using corn stover as the lignocellulose feedstock. The technoeconomic assessment for a cellulase enzyme production plant in the US Gulf Coast (USGC) region, producing 8.5 MMlb/y of cellulase enzyme complex from 57.87 MMlb/y of corn stover (dry basis), is covered. Considering an integrated facility, this cellulase enzyme capacity is based on the requirement to produce 25 MMgal/y (164.72 MMlb/y) of bioethanol from 694.44 MMlb/y of dry corn stover. The required total corn stover feedstock (752.31 MMlb/y) is subjected to dilute acid pretreatment with steam, followed by pH adjustment with ammonia. The pretreated and ammonia-conditioned feedstock hydrolysate is proportionately used for the cellulase enzyme production unit, using *Trichoderma reesei* fungi, under submerged aerobic cultivation (fermentation). The produced cellulase enzyme complex is directly supplied to the on-site integrated bioethanol plant without extensive separation or concentration. A separate cost analysis is provided for the pretreatment of total biomass, cellulase enzyme production, and the cost of integrated bioethanol production using pretreated corn stover and on-site produced cellulase enzymes.

Along with the process technology, this review includes the process flow diagram (PFD), material balance, major equipment list with specifications, capital and operating expenditure, and the overall production cost for producing cellulase enzyme using corn stover as the lignocellulosic biomass. The economic evaluation presented is the Process Economics Program's (PEP) independent interpretation of the commercial process based on information presented in the open literature, such as patents, technical articles, etc. It may not reflect, in whole or in part, the actual plant configuration.

Contacts

Tanushri Sood

Senior Research Specialist, Process Economics Program
tanushri.sood@spglobal.com

Rajiv Narang

Executive Director, Process Economics Program
rajiv.narang@spglobal.com

CONTACTS

Europe, Middle East, Africa: +44 (0) 203 367 0681

Americas: +1 800 332 6077

Asia-Pacific: +60 4 296 1125

www.spglobal.com/commodityinsights/en

www.spglobal.com/en/enterprise/about/contact-us.html

© 2025 by S&P Global Inc. All rights reserved.

S&P Global, the S&P Global logo, S&P Global Commodity Insights, and Platts are trademarks of S&P Global Inc. Permission for any commercial use of these trademarks must be obtained in writing from S&P Global Inc.

You may view or otherwise use the information, prices, indices, assessments and other related information, graphs, tables and images ("Data") in this publication only for your personal use or, if you or your company has a license for the Data from S&P Global Commodity Insights and you are an authorized user, for your company's internal business use only. You may not publish, reproduce, extract, distribute, retransmit, resell, create any derivative work from and/or otherwise provide access to the Data or any portion thereof to any person (either within or outside your company, including as part of or via any internal electronic system or intranet), firm or entity, including any subsidiary, parent, or other entity that is affiliated with your company, without S&P Global Commodity Insights' prior written consent or as otherwise authorized under license from S&P Global Commodity Insights. Any use or distribution of the Data beyond the express uses authorized in this paragraph above is subject to the payment of additional fees to S&P Global Commodity Insights.

S&P Global Commodity Insights, its affiliates and all of their third-party licensors disclaim any and all warranties, express or implied, including, but not limited to, any warranties of merchantability or fitness for a particular purpose or use as to the Data, or the results obtained by its use or as to the performance thereof. Data in this publication includes independent and verifiable data collected from actual market participants. Any user of the Data should not rely on any information and/or assessment contained therein in making any investment, trading, risk management or other decision. S&P Global Commodity Insights, its affiliates and their third-party licensors do not guarantee the adequacy, accuracy, timeliness and/or completeness of the Data or any component thereof or any communications (whether written, oral, electronic or in other format), and shall not be subject to any damages or liability, including but not limited to any indirect, special, incidental, punitive or consequential damages (including but not limited to, loss of profits, trading losses and loss of goodwill).

ICE index data and NYMEX futures data used herein are provided under S&P Global Commodity Insights' commercial licensing agreements with ICE and with NYMEX. You acknowledge that the ICE index data and NYMEX futures data herein are confidential and are proprietary trade secrets and data of ICE and NYMEX or its licensors/suppliers, and you shall use best efforts to prevent the unauthorized publication, disclosure or copying of the ICE index data and/or NYMEX futures data.

Permission is granted for those registered with the Copyright Clearance Center (CCC) to copy material herein for internal reference or personal use only, provided that appropriate payment is made to the CCC, 222 Rosewood Drive, Danvers, MA 01923, phone +1-978-750-8400. Reproduction in any other form, or for any other purpose, is forbidden without the express prior permission of S&P Global Inc. For article reprints contact: The YGS Group, phone +1-717-505-9701 x105 (800-501-9571 from the U.S.).

For all other queries or requests pursuant to this notice, please contact S&P Global Inc. via email at ci.support@spglobal.com