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Industrial Enzymes — Cellulase Production for Bioethanol

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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 C_5-C_6 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.

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