June 2002 • NREL/TP-510-32438

Technical Report

Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover

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Appendix A

NREL Biofuels Process Design Database Description and Summary

Appendix A NREL Process Design Database Description and Summary

NREL's Process Engineering Team has developed a database of primary information on all of the equipment in the benchmark model. This database contains information about the cost, reference year, scaling factor, scaling characteristic, design information and back-up cost referencing. The information is stored in a secure database in the Biotechnology Center for Fuels and Chemicals and can be directly linked to the economic portion of the model. In addition to having all of the cost information used by the model, it has the ability to store documents pertaining to the piece of equipment. These include sizing and costing calculations and vendor information when available.

The following summarizes the important fields of information contained in the database. A partial listing of the information is attached for each piece of equipment. Additional information from the database is contained in the equipment cost listing in Appendix B.

Equipment Number:[AB]	Unique identifier, the first letter indicates the equipment type and the first number represents the process area, e.g., P-301 is a pump in Area 300
Equipment Name:[AB]	Descriptive name of the piece of equipment
Associated PFD:	PFD number on which the piece of equipment appears, e.g., PFD-P110-A101
Equipment Category:[A]	Code indicating the general type of equipment, e.g., PUMP
Equipment Type:[A]	Code indicating the specific type of equipment, e.g., CENTRIFUGAL for a pump
Equipment Description:[A]	Short description of the size or characteristics of the piece of equipment, e.g., 20 gpm, 82 ft head for a pump
Number Required:[B]	Number of duplicate pieces of equipment needed
Number Spares:[B]	Number of on-line spares
Scaling Stream:[B]	Stream number or other characteristic variable from the ASPEN model by which the equipment cost will be scaled
Base Cost:[B]	Equipment cost
Cost Basis:[A]	Source of the equipment cost, e.g., ICARUS or VENDOR
Cost Year:[B]	Year for which the cost estimate is based
Base for Scaling:[B]	Value of the scaling stream or variable used to obtain the base cost of the equipment
Base Type:	Type of variable used for scaling, e.g., FLOW, DUTY, etc.
Base Units:	Units of the scaling stream or variable, e.g., KG/HR, CAL/S
Installation Factor:[B]	Value of the installation factor. Installed Cost = Base Cost x Installation Factor
Installation Factor Basis:	Source of the installation factor value, e.g., ICARUS, VENDOR
Scale Factor Exponent:[B]	Value of the exponential scaling equation
Scale Factor Basis:	Source of the scaling exponent value, e.g., GARRETT, VENDOR
Material of Construction:[A]	Material of Construction
Notes:	Any other important information about the design or cost
Document:	Complete, multi-page document containing design calculations, vendor literature and quotations and any other important information. This is stored as an electronic document and can be pages from a spreadsheet other electronic sources or scanned information from vendors.
Design Date:	Original date for the design of this piece of equipment
Modified Date:	The system automatically marks the date in this field whenever any field is changed

[A] These fields are listed for all pieces of equipment in this Appendix.
[B] These fields are part of the equipment cost listing in Appendix B.

Equipment Number	Equipment Name	Equipment Category	Equipment Type	Equipment Description	Cost Basis	Install. Factor Basis	Scale Factor Basis	Material of Construction
PFD-P110-A101								
C-101	Bale Transport Conveyor	CONVEYOR	BELT	Bale Transport Conveyor, 400 ft long, 8' wide, 50 HP motor	HARRIS00	HARRIS00	DEFAULT	CS
C-102	Bale Unwrapping Conveyor	CONVEYOR	BELT	Bale Unwrapping Conveyor, 90 bale / hr	HARRIS00	HARRIS00	DEFAULT	CS
C-103	Belt Press Discharge Conveyor	CONVEYOR	BELT	Belt Press Discharge Conveyor, 3' wide X 50' long.	HARRIS00	HARRIS00	DEFAULT	CS
C-104	Shredder Feed Conveyor	CONVEYOR	BELT	Shredder Feed Conveyor, 8' wide X 30' long. 6001 lbs 31 fpm	HARRIS00	HARRIS00	DEFAULT	CS
M-101	Truck Scales	SCALE	TRUCK-SCALE	Truck Scales; 10' X 50' 50tn	HARRIS00	HARRIS00	DEFAULT	CONCRETE
M-102	Truck Unloading Forklift	VEHICLE	LOADER	Truck Unloading Propane Gas Forklift	HARRIS00	HARRIS00	ASSUMED	
M-103	Bale Moving Forklift	VEHICLE	LOADER	Bale Moving Propane Gas Forklift	HARRIS00	HARRIS00	ASSUMED	
M-104	Corn Stover Wash Table	SIZE-REDUCTION		Corn Stover Wash Table (55 ton/hr)	HARRIS00	HARRIS00	DEFAULT	A283
M-105	Shredder	SIZE-REDUCTION		Shredder (28 ton/hr)	HARRIS00	HARRIS00	DEFAULT	ALLOY STEEL
M-106	Concrete Feedstock-Storage Slab	MISCELLANEOUS	CONCRETE-SLAB	Concrete Feedstock-Storage Slab 350' X 538'	HARRIS00	HARRIS00	HARRIS00	CONCRETE
M-107	Polymer Feed System	MISCELLANEOUS	MISCELLANEOUS	Polymer Feed System	HARRIS00	HARRIS00	DEFAULT	CS
P-101	Wash Table Pump	PUMP	CENTRIFUGAL	2500 gpm, 50 ft head.	HARRIS00	HARRIS00	GARRETT	CS; RUBBER
P-102	Wash Water Pump	PUMP	CENTRIFUGAL	5000 gpm, 50 ft head.	HARRIS00	HARRIS00	GARRETT	CS; SS316
P-103	Clarifier Underflow Pump	PUMP	RECIPROCATING	Clarifier Underflow Pump MOD SRL 2X3-10 100 GPM -- 50 TDH	HARRIS00	HARRIS00	GARRETT	CS; RUBBER
P-104	Clarified Water Pump	PUMP	CENTRIFUGAL	5000 gpm, 50 ft head.	HARRIS00	HARRIS00	GARRETT	CS; SS316
P-105	Belt Press Sump Pump	PUMP	SLURRY	Belt Press Sump Pump VJC 1.5X2.11 100 GPM -- 40 TDH	HARRIS00	HARRIS00	GARRETT	CS
S-101	Clarifier Thickener	SEPARATOR		Clarifier Thickener 5000 GPM mechanism	HARRIS00	HARRIS00	DEFAULT	CS
S-102	Belt Press	S/L SEPARATION	FILTER-PRESS	Belt Press 1.5 meter	HARRIS00	HARRIS00	DEFAULT	304SS; FILTER
S-103	Magnetic Separator	SEPARATOR	MAGNET	Tramp iron magnet separator.	VENDOR	DELTA-T98	DEFAULT	
T-101	Wash Water Tank	TANK	VERTICAL-VESSEL	Wash Water Tank (20' Diameter X 22' Tall, 50,000 gal)	HARRIS00	HARRIS00	GARRETT	CS
T-102	Clarifier Thickener Tank	TANK	CLARIFER	Clarifier Thickener Tank (80' diameter)	HARRIS00	HARRIS00	GARRETT	CEMENT
PFD-P110-A201-3								
A-201	In-line Sulfuric Acid Mixer	MIXER	STATIC	Static Mixer, 248 gpm total flow.	ICARUS	DELTA-T98	ICARUS	SS304
A-205	Hydrolysate Mix Tank Agitator	AGITATOR	FIXED-PROP	Top-Mounted, 1800 rpm, 50 hp	ICARUS	DELTA-T98	GARRETT	SS
A-209	Overliming Tank Agitator	AGITATOR	FIXED-PROP	Top Mounted, 1800 rpm, 25 hp	ICARUS	DELTA-T98	GARRETT	SS
A-224	Reacidification Tank Agitator	AGITATOR	FIXED-PROP	Top-Mounted, 1800 rpm, 93 hp	ICARUS	DELTA-T98	GARRETT	SS
A-232	Reslurrying Tank Agitator	AGITATOR	FIXED-PROP	Top-Mounted, 1800 rpm, 50 hp	ICARUS	DELTA-T98	GARRETT	SS
C-201	Hydrolyzate Screw Conveyor	CONVEYOR	SCREW	18" dia. X 33' long, 7600 cfh max flow	ICARUS	DELTA-T98	GARRETT	SS316
C-202	Hydrolysate Washed Solids Belt Conveyor	CONVEYOR	BELT	4' X 60' belt conveyor	HARRIS00	HARRIS00	GARRETT	
C-225	Lime Solids Feeder	CONVEYOR	ROTARY-VALVE	8" dia., 140 cfh, 7000 lb/hr max flow	ICARUS	DELTA-T98		A285C
H-200	Hydrolyzate Cooler	HEATX	SHELL-TUBE	Fixed Tube Sheet,1990 sf, 27'' dia. X 20' long	ICARUS	DELTA-T98	GARRETT	304SS;CS
H-201	Beer Column Feed Economizer	HEATX	SHELL-TUBE	Floating Head, 6266 sf, 48" dia x 23' long	ICARUS	DELTA-T98	GARRETT	304SS
H-205	Pneumapress Vent Condensor	HEATX	SHELL-TUBE	Fixed Tube Sheet, 120 sf, CS construction	ICARUS	DELTA-T98	GARRETT	CS
H-244	Waste Vapor Condensor	HEATX	SHELL-TUBE	Floating Head, 6266 sf, 48" dia x 23' long	ICARUS	DELTA-T98	GARRETT	304SS
M-202	Prehydrolysis/Screw Feeder/Impregnator Reactor	REACTOR	SCREW	Vertical Screw, 10 min residence time	VENDOR	CHEMSYST94	GARRETT	HASTELLOY-C 200;SS316L
P-201	Sulfuric Acid Pump	PUMP	CENTRIFUGAL	4 gpm, 245 ft. head	ICARUS	DELTA-T98	GARRETT	SS304
P-205	Pneumapress Feed Pump	PUMP	CENTRIFUGAL	Goulds Mod 3196 ^X8-13 1000 gpm 60 ft TDH 25 hp 1200 RPM	HARRIS00	HARRIS00	GARRETT	SS316
P-209	Overlimed Hydrolyzate Pump	PUMP	CENTRIFUGAL	687 gpm, 150 ft. head	ICARUS	DELTA-T98	GARRETT	304SS
P-211	Primary Filtrate Pump	PUMP	CENTRIFUGAL	Goulds Mod 3410 10X12-17 1000 GPM 60 ft TDH	HARRIS00	HARRIS00	GARRETT	SS316
P-213	Wash Filtrate Pump	PUMP	CENTRIFUGAL	Goulds Mod 3410 10X12-17 6000 GPM 200 ft TDH	HARRIS00	HARRIS00	GARRETT	SS316
P-222	Filtered Hydrolyzate Pump	PUMP	CENTRIFUGAL	721 gpm, 150 ft head	ICARUS	DELTA-T98	GARRETT	304SS
P-223	Lime Unloading Blower	FAN	CENTRIFUGAL	7425 cfm, 6 psi, 22275 lb/hr	DELTA-T98	DELTA-T98	GARRETT	C.S.
P-224	Fermentation Feed Pump	PUMP	ROTARY-LOBE	737 gpm, 200 ft head	VENDOR	ICARUS	VENDOR	304SS
P-239	Reacidified Liquor Pump	PUMP	CENTRIFUGAL	720 gpm, 100 ft head	ICARUS	DELTA-T98	GARRETT	SS304
S-205	Pneumapress Filter	SEPARATOR	PNEUMAPRESS	MOD 30-12-316 285 GPM 360 SQ FT AREA	HARRIS00	HARRIS00	DEFAULT	SS316
S-222	Hydroclone & Rotary Drum Filter	S/L SEPARATOR	ROTARY-DRUM	Hydrocyclone and Vacuum Filter	VENDOR	DELTA-T98	GARRETT	EPOXY LINED
S-227	LimeDust Vent Baghouse	SEPARATOR	FABRIC-FILTER	8333 cfm, 1389 sf, 6 cfm/sf	ICARUS	DELTA-T98	ICARUS	A285C;POLYESTER
T-201	Sulfuric Acid Storage	TANK	VERTICAL-VESSEL	6444 gal., 24 hr. residence time, 90% wv	DELTA-T98	DELTA-T98	GARRETT	PLASTIC
T-203	Blowdown Tank	TANK	VERTICAL-VESSEL	14500 gal., 11' dia x 30' high, 10 min. res. time, 75% wv, 15 psig	ICARUS	ICARUS	GARRETT	SS316
T-205	Hydrolysate Mixing Tank	TANK	FLAT-BTM-STORAGE	Modeled after Tank T-232 in Enzyme Process. 15 min. res. Time	ICARUS	DELTA-T98	GARRETT	SS304
T-209	Overliming Tank	TANK	VERTICAL-VESSEL	46200 gal., 16' dia. X 32' high, 1 hr. res. time, 90% wv, 15 psig	ICARUS	DELTA-T98	GARRETT	SS304
T-211	Primary Filtrate Tank	TANK	VERTICAL-VESSEL	12'6" D X 13' high 12,000 gal	HARRIS00	HARRIS00	GARRETT	SS316
T-213	Wash Filtrate Tank	TANK	VERTICAL-VESSEL	10' D X 11' high 6000 gal	HARRIS00	HARRIS00	GARRETT	SS316
T-220	Lime Storage Bin	TANK	LIVE-BTM-BIN	4455 cf, 14' dia x 25' high, 1.5x rail car vol., atmospheric	ICARUS	DELTA-T98	ICARUS	CS
T-224	Reacidification Tank	TANK	FLAT-BTM-STORAGE	185200 gal., 32' dia x 32' high, 4 hr. res. time, 90% wv, atmospheric	ICARUS	DELTA-T98	GARRETT	SS304
T-232	Slurrying Tank	TANK	FLAT-BTM-STORAGE	24770 gal., 13' dia. X 25' high, 15 min. res. time, 90% wv, atmospheric	ICARUS	DELTA-T98	GARRETT	SS304

Note: Equipment sizes listed are for a base case and may have been scaled up or down in the final cost estimation.

Equipment Number	Equipment Name	Equipment Category	Equipment Type	Equipment Description	Cost Basis	Install. Factor Basis	Scale Factor Basis	Material of Construction
PFD-P110-A301-2								
A-300	Ethanol Fermentor Agitator	AGITATOR	FIXED-PROP	Side Mounted, 2 per vessel, 75 hp each, 0.15 hp/1000 gal	DELTA-T98	DELTA-T98		SS304
A-301	Seed Hold Tank Agitator	AGITATOR	FIXED-PROP	Top Mounted, 1800 rpm, 23 hp, 0.1 hp/1000 gal	DELTA-T98	DELTA-T98	GARRETT	SS304
A-304	4th Seed Vessel Agitator	AGITATOR	FIXED-PROP	Top Mounted, 1800 rpm, 6 hp, 0.3 hp/1000 gal	ICARUS	DELTA-T98	GARRETT	SS
A-305	5th Seed Vessel Agitator	AGITATOR	FIXED-PROP	Top Mounted, 1800 rpm, 19 hp, 0.1 hp/1000 gal	DELTA-T98	DELTA-T98	GARRETT	SS
A-306	Beer Surge Tank Agitator	AGITATOR	FIXED-PROP	Top Mounted, 1800 rpm, 4 hp, 0.3 hp/1000 gal	ICARUS	DELTA-T98	GARRETT	SS304
A-310	Saccharification Tank Agitator	AGITATOR	FIXED-PROP	Side Mounted, 2 per vessel, 75 hp each, 0.15 hp/1000 gal	DELTA-T98	DELTA-T98		SS304
F-300	Ethanol Fermentor	TANK	FLAT-BTM-STORAGE	962,651 gal. each, 7 day residence total, 90% wv, API, atmospheric	VENDOR	DELTA-T98	MULTI-UNIT	SS304
F-301	1st Seed Fermentor	REACTOR	VERTICAL-VESSEL	20 gal, jacketed, agitated, 1.3' dia., 2' high, 15 psig	ICARUS	DELTA-T98		SS304
F-302	2nd Seed Fermentor	REACTOR	VERTICAL-VESSEL	194 gal., jacketed, agitated, 3' dia., 4' high, 2.5 psig	ICARUS	ICARUS		SS304
F-303	3rd Seed Fermentor	REACTOR	VERTICAL-VESSEL	1950 gal., jacketed, agitated, 6.5' dia, 8' high, 2.5 psig	ICARUS	DELTA-T98		SS304
F-304	4th Seed Fermentor	REACTOR	FLAT-BTM-STORAGE	19444 gal., 12' dia x 23' high, atmospheric	ICARUS	DELTA-T98	GARRETT	SS304
F-305	5th Seed Fermentor	REACTOR	FLAT-BTM-STORAGE	194500 gal., API, atmospheric	VENDOR	DELTA-T98	GARRETT	SS304
H-300	Fermentation Cooler	HEATX	PLATE-FRAME	2393 sf, 300 BTU/hr sf F	ICARUS	DELTA-T98	GARRETT	SS304
H-301	Hydrolyzate Heater	HEATX	PLATE-FRAME	773 sf, 300 BTU/hr sf F	DELTA-T98	DELTA-T98	GARRETT	SS304
H-302	Saccharified Slurry Cooler	HEATX	PLATE-FRAME	3765 sf total, 1255 sf each, 300 BTU/hr sf F	DELTA-T98	DELTA-T98	GARRETT	SS304
H-304	4th Seed Fermentor Coils	HEATX	IMMERSED-COIL	27 sf, 1" sch 40 pipe, 105 BTU/hr sf F	ICARUS	DELTA-T98	ICARUS	SS
H-305	5th Seed Fermentor Coils	HEATX	IMMERSED-COIL	307 sf, 3" sch 40 pipe, 92 BTU/hr sf F	ICARUS	DELTA-T98	ICARUS	SS
H-310	Fermentation Cooler	HEATX	PLATE-FRAME	2393 sf, 300 BTU/hr sf F	ICARUS	DELTA-T98	GARRETT	SS304
P-300	Fermentation Recirculation and Transfer Pump	PUMP	CENTRIFUGAL	1060 gpm, 150 ft head	ICARUS	DELTA-T98	GARRETT	SS304
P-301	Seed Hold Transfer Pump	PUMP	ROTARY-LOBE	172 gpm, 150 ft head	VENDOR	CHEMSYST94	VENDOR	SS304
P-302	Seed Transfer Pump	PUMP	ROTARY-LOBE	1231 gpm total, 615 gpm each, 100 ft head	VENDOR	CHEMSYST94	VENDOR	SS304
P-306	Beer Transfer Pump	PUMP	CENTRIFUGAL	1632 gpm each, 171 ft head	ICARUS	DELTA-T98	GARRETT	SS304
P-310	Saccharification Recirculation and Transfer Pump	PUMP	CENTRIFUGAL	1060 gpm, 150 ft head	ICARUS	DELTA-T98	GARRETT	SS304
T-301	Seed Hold Tank	TANK	FLAT-BTM-STORAGE	233,333 gal., API atmospheric	VENDOR	DELTA-T98	GARRETT	SS304
T-306	Beer Storage Tank	TANK	FLAT-BTM-STORAGE	456617 gal., 45' dia x 40' high, 4 hr res. Time, 90% wv, atmospheric	ICARUS	DELTA-T98	GARRETT	SS304
T-310	Saccharification Tank	TANK	FLAT-BTM-STORAGE	962,651 gal. each, 7 day residence total, 90% wv, API, atmospheric	VENDOR	DELTA-T98	MULTI-UNIT	SS304
PFD-P110-A501-5								
A-530	Recycled Water Tank Agitator	AGITATOR	FIXED-PROP	5 hp, 50 rpm,	VENDOR	DELTA-T98	GARRETT	CS
C-501	Lignin Wet Cake Screw	CONVEYOR	SCREW	14" Dia X 100' Long	ICARUS	DELTA-T98	GARRETT	CS
D-501	Beer Column	COLUMN	DISTILLATION	13.5' dia, 32 Actual Trays, Nutter V-Grid Trays	ICARUS	DELTA-T98	ICARUS	SS304
D-502	Rectification Column	COLUMN	DISTILLATION	11.5' dia.(rect)., 4' dia. (strip) x 18" T.S., 60 act. Trays, 60% eff., Nutter V-Grid trays	DELTA-T98	DELTA-T98	ICARUS	SS
E-501	1st Effect Evaporation	HEATX	SHELL-TUBE	22280 sf each., 135 BTU/hr sf F	DELTA-T98	DELTA-T98	GARRETT	SS316
E-502	2nd Effect Evaporation	HEATX	SHELL-TUBE	22278 sf., 170 BTU/hr sf F	DELTA-T98	DELTA-T98	GARRETT	SS316
E-503	3rd Effect Evaporation	HEATX	SHELL-TUBE	22278 sf each., 170 BTU/hr sf F	DELTA-T98	DELTA-T98	GARRETT	SS316
H-501	Beer Column Reboiler	HEATX	SHELL-TUBE	Fixed TS, 13899 sf, 41" dia., 20' long, 178 BTU/hr sf F	DELTA-T98	DELTA-T98	GARRETT	SS304;CS
H-502	Rectification Column Reboiler	HEATX	SHELL-TUBE	Thermosyphon, 1089 sf, 20" dia., 20' long, 130 BTU/hr sf F	ICARUS	DELTA-T98	GARRETT	SS304;CS
H-504	Beer Column Condenser	HEATX	SHELL-TUBE	Floating Head, 880 sf, 20" dia., 22' long, 92 BTU/hr sf F	DELTA-T98	DELTA-T98	GARRETT	SS304;CS
H-505	Rectification Column Condenser	HEATX	SHELL-TUBE	Fixed TS, 4146 sf, 39" dia, 20' long, 157 BTU/hr sf F	DELTA-T98	DELTA-T98	GARRETT	SS304;CS
H-512	Beer Column Feed Interchange	HEATX	PLATE-FRAME	909 sf, 200 BTU/hr sf F	DELTA-T98	DELTA-T98	GARRETT	SS
H-517	Evaporator Condenser	HEATX	SHELL-TUBE	Fixed TS, 8223 sf, 39" dia., 20' long, 220 BTU/hr sf F	DELTA-T98	DELTA-T98	GARRETT	SS304;CS
M-503	Molecular Sieve (9 pieces)	MISCELLANEOUS	PACKAGE	Superheater, twin mole sieve columns, product cooler, condenser, pumps, vacuum system	VENDOR	DELTA-T98		SS
P-501	Beer Column Bottoms Pump	PUMP	CENTRIFUGAL	5053 gpm, 150 ft head	ICARUS	ICARUS	GARRETT	SS
P-503	Beer Column Reflux Pump	PUMP	CENTRIFUGAL	12 gpm, 140 ft head	DELTA-T98	DELTA-T98	GARRETT	SS
P-504	Rectification Column Bottoms Pump	PUMP	CENTRIFUGAL	154 gpm, 158 ft head	DELTA-T98	DELTA-T98	GARRETT	SS
P-505	Rectification Column Reflux Pump	PUMP	CENTRIFUGAL	437 gpm, 110 ft head	DELTA-T98	DELTA-T98	GARRETT	SS
P-511	1st Effect Pump	PUMP	CENTRIFUGAL	2393 gpm each, 110 ft head	ICARUS	DELTA-T98	GARRETT	SS
P-512	2nd Effect Pump	PUMP	CENTRIFUGAL	1261 gpm, 110 ft head	ICARUS	DELTA-T98	GARRETT	SS
P-513	3rd Effect Pump	PUMP	CENTRIFUGAL	412 gpm each, 110 ft head	ICARUS	DELTA-T98	GARRETT	SS
P-514	Evaporator Condensate Pump	PUMP	CENTRIFUGAL	617 gpm, 125 ft head	ICARUS	DELTA-T98	GARRETT	SS304
P-515	Scrubber Bottoms Pump	PUMP	CENTRIFUGAL	69 gpm, 104 ft head	DELTA-T98	DELTA-T98	GARRETT	SS
P-530	Recycled Water Pump	PUMP	CENTRIFUGAL	790 gpm, 150 ft head	ICARUS	DELTA-T98	GARRETT	CS
S-505	Pneumapress Filter	SEPARATOR	PNEUMAPRESS	3@MOD 30-10-316 285 GPM 300 SQ FT AREA & 1@MOD 30-11-316 314 GPM 3[illegible] AREA	HARRIS00	HARRIS00	DEFAULT	SS316
T-503	Beer Column Relfux Drum	TANK	HORIZONTAL-VESSEL	346 gal, 15 min res. Time, 50% wv, 3' dia., 6.5' long, 25 psig	ICARUS	DELTA-T98	GARRETT	SS304
T-505	Rectification Column Reflux Drum	TANK	HORIZONTAL-VESSEL	13106 gal, 15 min res time, 50% wv, 9' dia, 27.5' long, 25 psig	ICARUS	DELTA-T98	GARRETT	SS304
T-512	Vent Scrubber	COLUMN	ABSORBER	7' dia x 25' high, 4 stages, plastic Jaeger Tri-Packing	DELTA-T98	DELTA-T98	GARRETT	SS304;PLASTIC
T-514	Evaporator Condensate Drum	TANK	HORIZONTAL-VESSEL	10233 gal, 10 min res. Time, 75% wv, 9' dia., 21.5' long, 1 psig	ICARUS	DELTA-T98	GARRETT	SS304
T-530	Recycled Water Tank	TANK	FLAT-BTM-STORAGE	13218 gal, Residence time 20 min, 2.5 psig	VENDOR	DELTA-T98	VENDOR	CS

Note: Equipment sizes listed are for a base case and may have been scaled up or down in the final cost estimation.

Equipment Number	Equipment Name	Equipment Category	Equipment Type	Equipment Description	Cost Basis	Install. Factor Basis	Scale Factor Basis	Material of Construction
PFD-P110-A601-2								
A-602	Equalization Basin Agitator	AGITATOR	FIXED-PROP	38 hp each, Fixed Prop, 0.1 hp/1000 gal	ICARUS	DELTA-T98	GARRETT	SS
A-606	Anaerobic Agitator	AGITATOR	FIXED-PROP	Fixed Prop, 41 hp, 0.05 hp/1000 gal	ICARUS	DELTA-T98	GARRETT	SS
A-608	Aerobic Lagoon Agitators	AGITATOR	SURFACE-AERATOR	Twister Surface Aerators, 50 HP ea	VENDOR	MERRICK98	GARRETT	CS
C-614	Aerobic Sludge Screw	CONVEYOR	SCREW	9" Dia X 25' Long	ICARUS	DELTA-T98	GARRETT	CS
H-602	Anaerobic Digestor Feed Cooler	HEATX	SHELL-TUBE	TEMA BES Type, Floating Head	ICARUS	DELTA-T98	VENDOR	SS316;CS
M-604	Nutrient Feed System	MISCELLANEOUS	PACKAGE	5 Tanks and Pumps	VENDOR	VENDOR		CS
M-606	Biogas Emergency Flare	MISCELLANEOUS	MISCELLANEOUS	Flare and Pilot	VENDOR	VENDOR	DEFAULT	SS
M-612	Filter Precoat System	MISCELLANEOUS	MISCELLANEOUS	Tank, Agitator, Pump	MERRICK98			CS
P-602	Anaerobic Reactor Feed Pump	PUMP	CENTRIFUGAL	876 gpm, 150 ft head	ICARUS	DELTA-T98	GARRETT	CS
P-606	Aerobic Digestor Feed Pump	PUMP	CENTRIFUGAL	830 gpm, 150 ft head	ICARUS	DELTA-T98	GARRETT	CS
P-608	Aerobic Sludge Recycle Pump	PUMP	SLURRY	2.5 gpm, 150 ft head	ICARUS	DELTA-T98	GARRETT	SS316
P-610	Aerobic Sludge Pump	PUMP	SLURRY	25.3 gpm, 150 ft head	ICARUS	DELTA-T98	GARRETT	SS316
P-611	Aerobic Digestion Outlet Pump	PUMP	CENTRIFUGAL	828 gpm, 150' head	ICARUS	DELTA-T98	GARRETT	CS
P-614	Sludge Filtrate Recycle Pump	PUMP	CENTRIFUGAL	22 gpm, 150' head	ICARUS	DELTA-T98	GARRETT	CS
P-616	Treated Water Pump	PUMP	CENTRIFUGAL	803 gpm, 100 ft head	ICARUS	DELTA-T98	GARRETT	CS
S-600	Bar Screen	SEPARATOR	SCREEN	0.5" Mech. cleaned Screen	CH2MHL91	DELTA-T98	ASSUMED	CS
S-614	Belt Filter Press	S/L SEPARATOR	FILTER-PRESS	BELT THICKNESS	VENDOR	VENDOR	VENDOR	304SS;BUNA N
T-602	Equalization Basin	TANK	FLAT-BTM-STORAGE	377516 gal, Residence time 7.2 hr,	VENDOR	VENDOR	GARRETT	CONCRETE
T-606	Anaerobic Digestor	TANK	FLAT-BTM-STORAGE	810250 gal each, space velocity 12g COD/L/DAY	VENDOR	VENDOR	GARRETT	EPOXY-LINED
T-608	Aerobic Digestor	REACTOR	LINED-PIT	19500000 gal, 16.3 day residence time	MERRICK98	MERRICK98		POLYMER LINED
T-610	Clarifier	SEPARATOR	CLARIFIER	195289 gal, Residence time 3.9 hr.	VENDOR	VENDOR	GARRETT	CONCRETE
PFD-P110-A701								
A-701	Denaturant In-line Mixer	MIXER	STATIC	Static Mixer, total flow 341 gpm	ICARUS	DELTA-T98	ICARUS	SS304
A-720	CSL Storage Tank Agitator	AGITATOR	FIXED-PROP	Top Mounted, 1800 rpm, 23 hp, 0.1 hp/1000 gal	DELTA-T98	DELTA-T98	GARRETT	SS304
A-760	CSL/DAP Day Tank Agitator	AGITATOR	FIXED-PROP	Top Mounted, 1800 rpm, 5 hp, 0.5 hp/1000 gal	ICARUS	DELTA-T98	GARRETT	SS304
C-755	DAP Solids Feeder	CONVEYOR	ROTARY-VALVE	8" dia., 140 cfh, 7000 lb/hr max flow	ICARUS	DELTA-T98		A285C
P-701	Ethanol Product Pump	PUMP	CENTRIFUGAL	324 gpm, 112 ft head	ICARUS	DELTA-T98	GARRETT	CS
P-703	Sulfuric Acid Pump	PUMP	CENTRIFUGAL	215 gpm, 150 ft head	ICARUS	DELTA-T98	GARRETT	SS316
P-704	Firewater Pump	PUMP	CENTRIFUGAL	2500 gpm, 50 ft head	ICARUS	DELTA-T98	GARRETT	CS
P-710	Gasoline Pump	PUMP	CENTRIFUGAL	17 gpm, 200 ft head	ICARUS	DELTA-T98	GARRETT	CS
P-720	CSL Pump	PUMP	CENTRIFUGAL	431 gpm, 150 ft head	ICARUS	DELTA-T98	GARRETT	CS
P-750	Cellulase Pump	PUMP	CENTRIFUGAL	2500 gpm, 50 ft head	ICARUS	DELTA-T98	GARRETT	CS
P-755	DAP Unloading Blower	FAN	CENTRIFUGAL	7425 cfm, 6 psi, 22275 lb/hr	DELTA-T98	DELTA-T98	GARRETT	CS
P-760	CSL/DAP Pump	PUMP	CENTRIFUGAL	431 gpm, 150 ft head	ICARUS	DELTA-T98	GARRETT	CS
S-755	DAP Vent Baghouse	SEPARATOR	FABRIC-FILTER	8333 cfm, 1389 sf, 6 cfm/sf	ICARUS	DELTA-T98	ICARUS	A285C;POLYESTER
T-701	Ethanol Product Storage Tank	TANK	FLAT-BTM-STORAGE	604,133 gal, 7 day res time total, 90% wv, 51' dia x 40' high, atmospheric	ICARUS	DELTA-T98	GARRETT	A285C
T-703	Sulfuric Acid Storage Tank	TANK	FLAT-BTM-STORAGE	18697 gal, 120 hr res time, 90% wv, 12' dia x 22' high, atmospheric	ICARUS	ICARUS	GARRETT	SS316
T-704	Firewater Storage Tank	TANK	FLAT-BTM-STORAGE	600,000 gal, 4 hr res time, 51' dia x 40' high, atmospheric	ICARUS	DELTA-T98	GARRETT	A285C
T-709	Propane Storage Tank	TANK	HORIZONTAL STORAGE	2000 gal, 10 day res time, 90% wv, 4' dia x 23.6' length, 250 psig	ICARUS	DELTA-T98	GARRETT	A515
T-710	Gasoline Storage Tank	TANK	FLAT-BTM-STORAGE	63,593 gal, 168 hr res time, 90% wv, 19' dia x 32' high, atmospheric	ICARUS	DELTA-T98	GARRETT	A285C
T-720	CSL Storage Tank	TANK	FLAT-BTM-STORAGE	71,918 gal, 120 hr res time, 90% wv, 20' dia x 32' high, atmospheric	ICARUS	ICARUS	GARRETT	SS304
T-750	Cellulase Storage Tank	TANK	FLAT-BTM-STORAGE	130,115 gal, 48 hr res time, 90% wv, 27' dia x 37' high, atmospheric	ICARUS	ICARUS	GARRETT	SS304
T-755	DAP Storage Bin	TANK	LIVE-BTM-BIN	1425 cf, 9' dia x 19.5' high, 1.5x vessel vol. Req. for 7-day res time, atmospheric	ICARUS	DELTA-T98	ICARUS	CS
T-760	CSL/DAP Day Tank	TANK	FLAT-BTM-STORAGE	10,000 gal, 24 hr res time, 90% wv, 9.5' dia x 18.9' high, atmospheric	ICARUS	ICARUS	GARRETT	SS304
PFD-P110-A801-4								
H-801	Burner Combustion Air Preheater	MISCELLANEOUS	MISCELLANEOUS	37000 sf combustion air/exhaust interchanger	ICARUS	NREL-ESTM	DEFAULT	
H-811	BFW Preheater	HEATX	SHELL-TUBE	Floating Head, 500 SF	ICARUS	DELTA-T98	GARRETT	SS304
M-803	Fluidized Bed Combustion Reactor	MISCELLANEOUS	MISCELLANEOUS	900 to 1250 psig/950F Circ. Fluid Bed	VENDOR	DELTA-T98	VENDOR	CS
M-804	Combustion Gas Baghouse	SEPARATOR	FABRIC-FILTER	Pulse Shaker, 545000 cfm, 135,135 SF	VENDOR	VENDOR	MULTI-UNIT	A285C;FABRIC
M-811	Turbine/Generator	GENERATOR	STEAM-TURBINE	52-61 MW; 281000 KG/HR STEAM	VENDOR	DELTA-T98	VENDOR	
M-820	Hot Process Water Softener System	MISCELLANEOUS	PACKAGE	1000 gpm flow, 24" dia softener. Includes filters, chemical feeders, piping, valves	RICHARDSON	NREL-ESTM	MULTI-UNIT	
M-830	Hydrazine Addition Pkg.	MISCELLANEOUS	PACKAGE	150 gal tank, agitator, 2 metering pumps	CHEMSYST94	CHEMSYST94	DEFAULT	
M-832	Ammonia Addition Pkg	MISCELLANEOUS	PACKAGE	150 gal tank, agitator, 2 metering pumps	CHEMSYST94	CHEMSYST94	DEFAULT	
M-834	Phosphate Addition Pkg.	MISCELLANEOUS	PACKAGE	150 gal tank, agitator, 2 metering pumps	CHEMSYST94	CHEMSYST94	DEFAULT	
P-804	Condensate Pump	PUMP	CENTRIFUGAL	272 gpm 150' head	ICARUS	DELTA-T98	GARRETT	SS316
P-811	Turbine Condensate Pump	PUMP	CENTRIFUGAL	175 gpm, 150 ft head.	ICARUS	DELTA-T98	GARRETT	SS304
P-824	Deaerator Feed Pump	PUMP	CENTRIFUGAL	650 gpm, 115 ft head.	ICARUS	DELTA-T98	GARRETT	SS304
P-826	BFW Pump	PUMP	CENTRIFUGAL	500 gpm, 2740 ft head.	VENDOR	DELTA-T98	GARRETT	SS316
P-828	Blowdown Pump	PUMP	CENTRIFUGAL	29 gpm, 150 ' head	ICARUS	DELTA-T98	GARRETT	CS
P-830	Hydrazine Transfer Pump	PUMP	CENTRIFUGAL	5 gpm, 75 ft head	DELTA-T98	DELTA-T98	GARRETT	CS
T-804	Condensate Collection Tank	TANK	VERTICAL-VESSEL	1600 gal, Residence time 1.5 minutes, atmospheric	ICARUS	DELTA-T98	GARRETT	A285C
T-824	Condensate Surge Drum	TANK	HORIZONTAL-VESSEL	11,400 gal, 24' x 9'dia, 15psig, Residence time 11 min.	ICARUS	DELTA-T98	GARRETT	SS304
T-826	Deaerator	TANK	HORIZONTAL-VESSEL	18,170 gal hold tank, 150 psig design pressure, 10 min residence time	VENDOR	CHEMSYST94	GARRETT	CS;SS316
T-828	Blowdown Flash Drum	TANK	HORIZONTAL-VESSEL	424 gal, 4.5' x 4'dia, 15 psig	ICARUS	DELTA-T98	GARRETT	CS
T-830	Hydrazine Drum	TANK	VERTICAL-VESSEL	260 gal, 4.9' x 3'dia., 10psig	ICARUS	DELTA-T98	GARRETT	SS316

Note: Equipment sizes listed are for a base case and may have been scaled up or down in the final cost estimation.

Equipment Number	Equipment Name	Equipment Category	Equipment Type	Equipment Description	Cost Basis	Install. Factor Basis	Scale Factor Basis	Material of Construction
PFD-P110-A901-3								
M-902	Cooling Tower System	COOLING-TOWER	INDUCED-DRAFT	71000 gpm, 147.8 x E6 kcal/hr, 5 cell	DELTA-T98	DELTA-T98	GARRETT	FIBERGLASS
M-904	Plant Air Compressor	COMPRESSOR	RECIPROCATING	450 cfm, 125 psig outlet	ICARUS	DELTA-T98	GARRETT	CS
M-910	CIP System	MISCELLANEOUS	MISCELLANEOUS	Designed by Delta-T. Same cost as sum of previous units.	DELTA-T98	DELTA-T98	NREL-ESTM	CS
P-902	Cooling Water Pumps	PUMP	CENTRIFUGAL	41000 gpm, 70 ft head.	ICARUS	DELTA-T98	GARRETT	CS
P-912	Make-up Water Pump	PUMP	CENTRIFUGAL	1083 gpm, 75 ft. head	ICARUS	DELTA-T98	GARRETT	CS
P-914	Process Water Circulating Pump	PUMP	CENTRIFUGAL	1199 gpm ea, 75 ft. head	ICARUS	DELTA-T98	GARRETT	CS
S-904	Instrument Air Dryer	DRYER	PACKAGE	400 SCFM Air Dryer, -40F Dewpoint	RICHARDSON	DELTA-T98	DEFAULT	CS
T-902	Pretreatment Pressure Filter Press Air Receiver	TANK	HORIZONTAL-PRESSURE	300 gal	HARRIS00	HARRIS00	GARRETT	CS
T-904	Plant Air Receiver	TANK	HORIZONTAL-VESSEL	900 gal., 200 psig	ICARUS	DELTA-T98	GARRETT	CS
T-905	Product Recovery Pressure Filter Press Air Receiver	TANK	HORIZONTAL-PRESSURE	300 gal	HARRIS00	HARRIS00	GARRETT	CS
T-914	Process Water Tank	TANK	FLAT-BTM-STORAGE	756000 gal. 8 hr res time	ICARUS	DELTA-T98	GARRETT	CS

Note: Equipment sizes listed are for a base case and may have been scaled up or down in the final cost estimation.

Appendix B

Individual Equipment Costs Summary

Individual Equipment Cost Summary

Equipment Number	Number Required	Number Spares	Equipment Name	Scaled On	Size Ratio (Base/ Current)	Original Equip Cost (per unit)	Base Year	Total Original Equip Cost (Req'd & Spare) in Base Year	Scaling Exponent	Scaled Cost in Base Year	Installation Factor	Installed Cost in Base Year	Installed Cost in 2000$
C-101	2		Bale Transport Conveyor	Flow	1.00	$400,000	2000	$800,000	0.6	$799,996	1.62	$1,295,994	$1,295,994
C-102	2		Bale Unwrapping Conveyor	Flow	1.00	$150,000	2000	$300,000	0.6	$299,999	1.19	$356,998	$356,998
C-103	1		Belt Press Discharge Conveyor	Flow	1.00	$50,000	2000	$50,000	0.6	$50,000	1.89	$94,500	$94,500
C-104	4		Shredder Feed Conveyor	Flow	1.00	$60,000	2000	$240,000	0.6	$239,999	1.38	$331,198	$331,198
M-101	2		Truck Scales	Flow	1.00	$34,000	2000	$68,000	0.6	$68,000	2.47	$167,959	$167,959
M-102	4	1	Truck Unloading Forklift	Flow	1.00	$18,000	2000	$90,000	1	$89,999	1	$89,999	$89,999
M-103	4		Bale Moving Forklift	Flow	1.00	$18,000	2000	$72,000	1	$71,999	1	$71,999	$71,999
M-104	2		Corn Stover Wash Table	Flow	1.00	$104,000	2000	$208,000	0.6	$207,999	2.39	$497,118	$497,118
M-105	4		Shredder	Flow	1.00	$302,000	2000	$1,208,000	0.6	$1,207,994	1.38	$1,667,032	$1,667,032
M-106	1		Concrete Feedstock-Storage Slab	Flow	1.00	$450,655	2000	$450,655	1	$450,651	2.2	$991,433	$991,433
M-107	1		Polymer Feed System	Flow	1.00	$30,000	2000	$30,000	0.6	$30,000	2.28	$68,400	$68,400
P-101	2	1	Wash Table Pump	Flow	1.00	$20,000	2000	$60,000	0.79	$60,000	3.87	$232,199	$232,199
P-102	2	1	Wash Water Pump	Flow	1.00	$15,000	2000	$45,000	0.79	$45,000	5.19	$233,549	$233,549
P-103	1	1	Clarifier Underflow Pump	Flow	1.00	$6,000	2000	$12,000	0.79	$12,000	13.41	$160,919	$160,919
P-104	1	1	Clarified Water Pump	Flow	1.00	$15,000	2000	$30,000	0.79	$30,000	7.07	$212,099	$212,099
P-105	1	1	Belt Press Sump Pump	Flow	1.00	$19,000	2000	$38,000	0.79	$38,000	2.92	$110,959	$110,959
S-101	1		Clarifier Thickener	Flow	1.00	$135,000	2000	$135,000	0.6	$134,999	1.51	$203,849	$203,849
S-102	1		Belt Press	Flow	1.00	$100,000	2000	$100,000	0.6	$100,000	1.25	$124,999	$124,999
S-103	1		Magnetic Separator	Flow	0.61	$13,863	1998	$13,863	0.6	$10,335	1.3	$13,435	$13,594
T-101	1		Wash Water Tank	Flow	1.00	$50,000	2000	$50,000	0.51	$50,000	2.8	$139,999	$139,999
T-102	1		Clarifier Thickener Tank	Flow	1.00	$135,000	2000	$135,000	0.51	$134,999	3.04	$410,398	$410,398
A100							**Subtotal***	**$4,135,518**		**$4,131,968**	1.81	**$7,475,036**	**$7,475,195**

*Sections are subtotaled and an average "Installation Factor" is back-calculated for the section.

Individual Equipment Cost Summary

Equipment Number	Number Required	Number Spares	Equipment Name	Scaled On	Size Ratio (Base/ Current)	Original Equip Cost (per unit)	Base Year	Total Original Equip Cost (Req'd & Spare) in Base Year	Scaling Exponent	Scaled Cost in Base Year	Installation Factor	Installed Cost in Base Year	Installed Cost in 2000$
A-201	1		In-line Sulfuric Acid Mixer	Flow	1.83	$1,900	1997	$1,900	0.48	$2,542	1	$2,542	$2,592
A-205	1		Hydrolyzate Mix Tank Agitator	Flow	0.63	$36,000	1997	$36,000	0.51	$28,421	1.2	$34,105	$34,775
A-209	1		Overliming Tank Agitator	Flow	1.62	$19,800	1997	$19,800	0.51	$25,349	1.3	$32,953	$33,601
A-224	1		Reacidification Tank Agitator	Flow	1.63	$65,200	1997	$65,200	0.51	$83,599	1.2	$100,318	$102,291
A-232	1		Reslurrying Tank Agitator	Flow	1.19	$36,000	1997	$36,000	0.51	$39,423	1.2	$47,308	$48,238
C-201	1		Hydrolyzate Screw Conveyor	Flow	1.00	$59,400	1997	$59,400	0.78	$59,518	1.3	$77,373	$78,895
C-202	1		Hydrolysate Washed Solids Belt Conveyor	Flow	0.95	$80,000	2000	$80,000	0.76	$77,213	1.45	$111,959	$111,959
C-225	1		Lime Solids Feeder	None		$3,900	1997	$3,900		$3,900	1.3	$5,070	$5,170
H-200	1		Hydrolyzate Cooler	Area	0.27	$45,000	1997	$45,000	0.51	$23,266	2.1	$48,859	$49,820
H-201	2	1	Beer Column Feed Economizer	Area	1.16	$132,800	1997	$398,400	0.68	$441,162	2.1	$926,441	$944,658
H-205	1		Pneumapress Vent Condensor	Area	0.84	$15,385	2000	$15,385	0.68	$13,620	2.1	$28,603	$28,603
H-244	2	1	Waste Vapor Condensor	Area	0.24	$132,800	1997	$398,400	0.68	$152,180	2.1	$319,578	$325,863
M-202	3		Prehydrolysis/Screw Feeder/Reactor	Flow	1.03	$2,457,487	2000	$7,372,462	0.6	$7,494,911	2.29	$17,163,347	$17,163,347
P-201	1	1	Sulfuric Acid Pump	Flow	2.00	$4,800	1997	$9,600	0.79	$16,577	2.8	$46,416	$47,328
P-205	2	1	Pneumapress Feed Pump	Solids Flow	0.95	$15,416	2000	$46,248	0.79	$44,579	3.34	$148,893	$148,893
P-209	1	1	Overlimed Hydrolyzate Pump	Flow	1.62	$10,700	1997	$21,400	0.79	$31,377	2.8	$87,855	$89,583
P-211	1	1	Primary Filtrate Pump	Flow	1.02	$32,549	2000	$65,098	0.79	$65,931	3.56	$234,716	$234,716
P-213	1	1	Wash Filtrate Pump	Flow	0.99	$49,803	2000	$99,606	0.79	$98,809	2.71	$267,772	$267,772
P-222	1	1	Filtered Hydrolyzate Pump	Flow	1.64	$10,800	1997	$21,600	0.79	$31,862	2.8	$89,214	$90,968
P-223	1		Lime Unloading Blower	Flow	4.38	$47,600	1998	$47,600	0.5	$99,594	1.4	$139,432	$141,078
P-224	2	1	Saccharification Feed Pump	Flow	1.19	$61,368	1998	$184,104	0.7	$208,550	2.8	$583,941	$590,837
P-239	1	1	Reacidified Liquor Pump	Flow	1.63	$10,800	1997	$21,600	0.79	$31,745	2.8	$88,886	$90,633
S-205	3		Pneumapress Filter	Solids Flow	0.95	$1,575,000	2000	$4,725,000	0.6	$4,594,911	1.05	$4,824,657	$4,824,657
S-222	1		Hydroclone & Rotary Drum Filter	Flow	1.39	$165,000	1998	$165,000	0.39	$187,567	1.4	$262,594	$265,695
S-227	1		LimeDust Vent Baghouse	Flow	4.37	$32,200	1997	$32,200	1	$140,707	1.5	$211,061	$215,211
T-201	1		Sulfuric Acid Tank	Flow	2.00	$5,760	1996	$5,760	0.71	$9,411	1.4	$13,175	$13,603
T-203	1		Blowdown Tank	Flow	1.03	$64,100	1997	$64,100	0.93	$65,987	1.2	$79,184	$80,741
T-205	1		Hydrolyzate Mixing Tank	Flow	0.63	$44,800	1997	$44,800	0.71	$32,237	1.2	$38,684	$39,445
T-209	1		Overliming Tank	Flow	1.62	$71,000	1997	$71,000	0.71	$100,144	1.4	$140,201	$142,958
T-211	1		Primary Filtrate Tank	Flow	1.02	$36,000	2000	$36,000	0.71	$36,414	2.45	$89,214	$89,214
T-213	1		Wash Filtrate Tank	Flow	0.99	$18,000	2000	$18,000	0.71	$17,870	3.68	$65,763	$65,763
T-220	1		Lime Storage Bin	Flow	4.37	$69,200	1997	$69,200	0.46	$136,370	1.3	$177,281	$180,767
T-224	1		Reacidification Tank	Flow	1.63	$147,800	1997	$147,800	0.51	$189,507	1.2	$227,409	$231,881
T-232	1		Slurrying Tank	Flow	1.19	$44,800	1997	$44,800	0.71	$50,839	1.2	$61,007	$62,207
A200							**Subtotal***	**$14,472,363**		**$14,636,094**	1.83	**$26,775,812**	**$26,843,763**

*Sections are subtotaled and an average "Installation Factor" is back-calculated for the section.

Individual Equipment Cost Summary

Equipment Number	Number Required	Number Spares	Equipment Name	Scaled On	Size Ratio (Base/ Current)	Original Equip Cost (per unit)	Base Year	Total Original Equip Cost (Req'd & Spare) in Base Year	Scaling Exponent	Scaled Cost in Base Year	Installation Factor	Installed Cost in Base Year	Installed Cost in 2000$
A-300	10		Ethanol Fermentor Agitator	None		$19,676	1996	$196,760		$196,760	1.2	$236,112	$243,782
A-301	1		Seed Hold Tank Agitator	Flow	0.99	$12,551	1996	$12,551	0.51	$12,492	1.2	$14,990	$15,477
A-304	2		4th Seed Vessel Agitator	Flow	0.99	$11,700	1997	$23,400	0.51	$23,289	1.2	$27,947	$28,497
A-305	2		5th Seed Vessel Agitator	Flow	0.99	$10,340	1996	$20,680	0.51	$20,582	1.2	$24,699	$25,501
A-306	2		Beer Surge Tank Agitator	Flow	1.18	$48,700	1998	$97,400	0.51	$105,852	1.2	$127,023	$128,523
A-310	10		Saccharification Tank Agitator	None		$19,676	1996	$196,760		$196,760	1.2	$236,112	$243,782
F-300	5		Ethanol Fermentor	None		$493,391	1998	$2,466,955		$2,466,955	1.2	$2,960,346	$2,995,308
F-301	2		1st Seed Fermentor	None		$14,700	1997	$29,400		$29,400	2.8	$82,320	$83,939
F-302	2		2nd Seed Fermentor	None		$32,600	1997	$65,200		$65,200	2.8	$182,560	$186,150
F-303	2		3rd Seed Fermentor	None		$81,100	1997	$162,200		$162,200	2.8	$454,160	$463,090
F-304	2		4th Seed Fermentor	Flow	0.99	$39,500	1997	$79,000	0.93	$78,320	1.2	$93,984	$95,832
F-305	2		5th Seed Fermentor	Flow	0.99	$147,245	1998	$294,490	0.51	$293,097	1.2	$351,717	$355,871
H-300	5	1	Fermentation Cooler	Heat Duty	1.97	$4,000	1997	$24,000	0.78	$40,684	2.1	$85,437	$87,117
H-301	1	1	Hydrolyzate Heater	Area	2.49	$19,040	1996	$38,080	0.68	$70,858	2.1	$148,802	$153,636
H-302	3		Saccharified Slurry Cooler	Area	0.85	$25,409	1998	$76,227	0.78	$67,038	2.1	$140,779	$142,441
H-304	1		4th Seed Fermentor Coil	Heat Duty	1.51	$3,300	1997	$3,300	0.83	$4,658	1.2	$5,589	$5,699
H-305	1		5th Seed Fermentor Coil	Heat Duty	1.51	$18,800	1997	$18,800	0.98	$28,238	1.2	$33,886	$34,552
H-310	5	1	Fermentation Cooler	Heat Duty	0.07	$4,000	1997	$24,000	0.78	$3,054	2.1	$6,413	$6,539
P-300	5	1	Fermentation Recirc/Transfer Pump	Heat Duty	1.97	$8,000	1997	$48,000	0.79	$82,000	2.8	$229,600	$234,115
P-301	1	1	Seed Hold Transfer Pump	Flow	0.99	$22,194	1998	$44,388	0.7	$44,100	1.4	$61,740	$62,469
P-302	2		Seed Transfer Pump	Flow	0.99	$54,088	1998	$108,176	0.7	$107,474	1.4	$150,464	$152,241
P-306	1	1	Beer Transfer Pump	Flow	1.18	$17,300	1997	$34,600	0.79	$39,360	2.8	$110,209	$112,376
P-310	5	1	Saccharification Recirc/Transfer Pump	Heat Duty	0.07	$8,000	1997	$48,000	0.79	$5,954	2.8	$16,671	$16,998
T-301	1		Seed Hold Tank	Flow	0.99	$161,593	1998	$161,593	0.51	$160,829	1.2	$192,995	$195,274
T-306	1		Beer Storage Tank	Flow	1.18	$237,700	1998	$237,700	0.71	$266,897	1.2	$320,276	$324,059
T-310	5		Saccharification Tank	None		$493,391	1998	$2,466,955		$2,466,955	1.2	$2,960,346	$2,995,308
A300							**Subtotal***	**$6,978,615**		**$7,039,007**	1.3	**$9,255,176**	**$9,388,577**

*Sections are subtotaled and an average "Installation Factor" is back-calculated for the section.

Individual Equipment Cost Summary

Equipment Number	Number Required	Number Spares	Equipment Name	Scaled On	Size Ratio (Base/ Current)	Original Equip Cost (per unit)	Base Year	Total Original Equip Cost (Req'd & Spare) in Base Year	Scaling Exponent	Scaled Cost in Base Year	Installation Factor	Installed Cost in Base Year	Installed Cost in 2000$
A-530	1		Recycled Water Tank Agitator	Flow	1.45	$5,963	1998	$5,963	0.51	$7,197	1.3	$9,356	$9,467
C-501	1		Lignin Wet Cake Screw	Flow	0.44	$31,700	1997	$31,700	0.78	$16,837	1.4	$23,571	$24,035
D-501	1		Beer Column	Diameter Squared	1.13	$478,100	1998	$478,100	0.68	$520,236	2.1	$1,092,496	$1,105,399
D-502	1		Rectification Column	Flow	1.25	$525,800	1996	$525,800	0.68	$613,596	2.1	$1,288,553	$1,330,413
E-501	2		1st Effect Evaporation	Area	1.70	$544,595	1996	$1,089,190	0.68	$1,560,371	2.1	$3,276,779	$3,383,230
E-502	1		2nd Effect Evaporation	Area	1.70	$435,650	1996	$435,650	0.68	$624,111	2.1	$1,310,634	$1,353,211
E-503	2		3rd Effect Evaporation	Area	1.70	$435,650	1996	$871,300	0.68	$1,248,222	2.1	$2,621,267	$2,706,422
H-501	1	1	Beer Column Reboiler	Heat Duty	1.19	$158,374	1996	$316,748	0.68	$357,008	2.1	$749,716	$774,072
H-502	1		Rectification Column Reboiler	Heat Duty	1.18	$29,600	1997	$29,600	0.68	$33,192	2.1	$69,703	$71,074
H-504	1		Beer Column Condenser	Heat Duty	0.37	$29,544	1996	$29,544	0.68	$15,042	2.1	$31,588	$32,614
H-505	1		Start-up Rect. Column Condenser	Heat Duty	1.39	$86,174	1996	$86,174	0.68	$107,911	2.1	$226,613	$233,975
H-512	1	1	Beer Column Feed Interchanger	Area	1.18	$19,040	1996	$38,080	0.68	$42,690	2.1	$89,650	$92,562
H-517	1	1	Evaporator Condenser	Heat Duty	1.75	$121,576	1996	$243,152	0.68	$355,539	2.1	$746,633	$770,888
M-503	1		Molecular Sieve (9 pieces)	Flow	1.20	$2,700,000	1998	$2,700,000	0.7	$3,075,992	1	$3,075,992	$3,112,319
P-501	1	1	Beer Column Bottoms Pump	Flow	1.20	$42,300	1997	$84,600	0.79	$97,723	2.8	$273,623	$279,004
P-503	1	1	Beer Column Reflux Pump	Heat Duty	0.37	$1,357	1998	$2,714	0.79	$1,239	2.8	$3,469	$3,510
P-504	1	1	Rectification Column Bottoms Pump	Flow	1.19	$4,916	1998	$9,832	0.79	$11,316	2.8	$31,685	$32,059
P-505	1	1	Rectification Column Reflux Pump	Heat Duty	1.39	$4,782	1998	$9,564	0.79	$12,418	2.8	$34,772	$35,182
P-511	2	1	1st Effect Pump	Flow	1.09	$19,700	1997	$59,100	0.79	$63,251	2.8	$177,103	$180,585
P-512	1	1	2nd Effect Pump	Flow	1.28	$13,900	1997	$27,800	0.79	$33,843	2.8	$94,759	$96,622
P-513	2	1	3rd Effect Pump	Flow	0.83	$8,000	1997	$24,000	0.79	$20,748	2.8	$58,095	$59,237
P-514	1	1	Evaporator Condensate Pump	Flow	1.69	$12,300	1997	$24,600	0.79	$37,312	2.8	$104,475	$106,529
P-515	1		Scrubber Bottoms Pump	Flow	2.41	$2,793	1998	$2,793	0.79	$5,604	2.8	$15,692	$15,878
P-530	1	1	Recycled Water Pump	Flow	1.45	$10,600	1997	$21,200	0.79	$28,372	2.8	$79,441	$81,003
S-505	4		Pneumapress Filter	Solids Flow	0.85	$1,418,750	2000	$5,675,000	0.6	$5,142,942	1.04	$5,348,660	$5,348,660
T-503	1		Beer Column Relfux Drum	Heat Duty	0.37	$11,900	1997	$11,900	0.93	$4,727	2.1	$9,927	$10,122
T-505	1		Rectification Column Reflux Drum	Heat Duty	1.39	$45,600	1997	$45,600	0.72	$57,855	2.1	$121,496	$123,885
T-512	1		Vent Scrubber	Flow	1.37	$99,000	1998	$99,000	0.78	$126,355	2.1	$265,346	$268,480
T-514	1		Evaporator Condensate Drum	Flow	1.44	$37,200	1998	$37,200	0.93	$52,286	2.1	$109,800	$111,097
T-530	1		Recycled Water Tank	Flow	1.45	$14,515	1998	$14,515	0.745	$19,106	1.4	$26,748	$27,064
A500							**Subtotal***	**$13,030,419**		**$14,293,042**	1.49	**$21,367,640**	**$21,778,596**

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Individual Equipment Cost Summary

Equipment Number	Number Required	Number Spares	Equipment Name	Scaled On	Size Ratio (Base/ Current)	Original Equip Cost (per unit)	Base Year	Total Original Equip Cost (Req'd & Spare) in Base Year	Scaling Exponent	Scaled Cost in Base Year	Installation Factor	Installed Cost in Base Year	Installed Cost in 2000$
A-602	1		Equalization Basin Agitator	Flow	0.52	$28,400	1997	$28,400	0.51	$20,286	1.2	$24,343	$24,822
A-606	1		Anaerobic Agitator	Volume	1.03	$30,300	1997	$30,300	0.51	$30,730	1.2	$36,875	$37,601
A-608	16		Aerobic Lagoon Agitator	Power	0.26	$31,250	1998	$500,000	0.51	$253,438	1.4	$354,813	$359,004
C-614	1		Aerobic Sludge Screw	Flow	0.22	$5,700	1997	$5,700	0.78	$1,768	1.4	$2,475	$2,524
H-602	1		Anaerobic Digestor Feed Cooler	Area	0.43	$128,600	1997	$128,600	0.74	$68,759	2.1	$144,393	$147,232
M-604	1		Nutrient Feed System	None		$31,400	1998	$31,400		$31,400	2.58	$81,012	$81,969
M-606	1		Biogas Emergency Flare	Flow	0.24	$20,739	1998	$20,739	0.6	$8,877	1.68	$14,914	$15,090
M-612	1		Filter Precoat System	None		$3,000	1998	$3,000		$3,000	1.4	$4,200	$4,250
P-602	1	1	Anaerobic Reactor Feed Pump	Flow	0.52	$11,400	1997	$22,800	0.79	$13,539	2.8	$37,910	$38,656
P-606	1	1	Aerobic Digestor Feed Pump	Flow	0.52	$10,700	1997	$21,400	0.79	$12,775	2.8	$35,771	$36,475
P-608	1		Aerobic Sludge Recycle Pump	Flow	0.22	$11,100	1997	$11,100	0.79	$3,356	1.4	$4,699	$4,791
P-610	1		Aerobic Sludge Pump	Flow	0.22	$11,100	1997	$11,100	0.79	$3,356	1.4	$4,699	$4,791
P-611	1	1	Aerobic Digestion Outlet Pump	Flow	0.52	$10,700	1997	$21,400	0.79	$12,707	2.8	$35,579	$36,278
P-614	1	1	Sludge Filtrate Recycle Pump	Flow	0.22	$6,100	1997	$12,200	0.79	$3,681	2.8	$10,306	$10,509
P-616	1	1	Treated Water Pump	Flow	0.53	$10,600	1997	$21,200	0.79	$12,772	2.8	$35,760	$36,463
S-600	1		Bar Screen	Flow	0.52	$117,818	1991	$117,818	0.3	$96,663	1.2	$115,996	$126,526
S-614	1		Belt Filter Press	COD	0.26	$650,223	1998	$650,223	0.72	$248,935	1.8	$448,083	$453,375
T-602	1		Equalization Basin	Flow	0.52	$350,800	1998	$350,800	0.51	$250,578	1.42	$355,821	$360,023
T-606	1		Anaerobic Digestor	Volume	1.03	$881,081	1998	$881,081	0.51	$893,571	1.04	$929,314	$940,289
T-608	1		Aerobic Digestor	Volume	0.52	$635,173	1998	$635,173	1	$330,629	1	$330,629	$334,534
T-610	1		Clarifier	Flow	0.52	$174,385	1998	$174,385	0.51	$124,991	1.96	$244,981	$247,875
A600							**Subtotal***	**$3,678,819**		**$2,425,810**	1.34	**$3,252,573**	**$3,303,075**

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Individual Equipment Cost Summary

Equipment Number	Number Required	Number Spares	Equipment Name	Scaled On	Size Ratio (Base/ Current)	Original Equip Cost (per unit)	Base Year	Total Original Equip Cost (Req'd & Spare) in Base Year	Scaling Exponent	Scaled Cost in Base Year	Installation Factor	Installed Cost in Base Year	Installed Cost in 2000$
A-701	1		Denaturant In-line Mixer	Flow	1.32	$1,900	1997	$1,900	0.48	$2,173	1	$2,173	$2,216
A-720	1		CSL Storage Tank Agitator	Flow	0.03	$12,551	1996	$12,551	0.51	$2,143	1.2	$2,572	$2,655
A-760	1		CSL/DAP Day Tank Agitator	Flow	0.93	$12,795	2001	$12,795	0.51	$12,348	1.2	$14,817	$14,582
C-755	1		DAP Solids Feeder	None		$3,900	1997	$3,900		$3,900	1.3	$5,070	$5,170
P-701	2	1	Ethanol Product Pump	Flow	1.33	$7,500	1997	$22,500	0.79	$28,200	2.8	$78,959	$80,512
P-703	1	1	Sulfuric Acid Pump	Flow	2.00	$8,000	1997	$16,000	0.79	$27,628	2.8	$77,359	$78,881
P-704	1	1	Firewater Pump	Flow	1.33	$18,400	1997	$36,800	0.79	$46,120	2.8	$129,137	$131,676
P-710	1	1	Gasoline Pump	Flow	1.15	$4,500	1997	$9,000	0.79	$10,041	2.8	$28,114	$28,667
P-720	1	1	CSL Pump	Flow	0.64	$8,800	1997	$17,600	0.79	$12,376	2.8	$34,652	$35,333
P-750	1	1	Cellulase Pump	Flow	1.00	$18,400	1997	$36,800	0.79	$36,803	2.8	$103,049	$105,075
P-755	1		DAP Unloading Blower	Flow	1.06	$47,600	1998	$47,600	0.5	$49,014	1.4	$68,620	$69,431
P-760	1	1	CSL/DAP Pump	Flow	0.64	$8,800	1997	$17,600	0.79	$12,376	2.8	$34,652	$35,333
S-755	1		DAP Vent Baghouse	Flow	0.30	$32,200	1997	$32,200	1	$9,595	1.5	$14,392	$14,675
T-701	2		Ethanol Product Storage Tank	Flow	1.33	$165,800	1997	$331,600	0.51	$383,637	1.4	$537,092	$547,654
T-703	1		Sulfuric Acid Storage Tank	Flow	2.00	$42,500	1997	$42,500	0.51	$60,470	1.2	$72,564	$73,991
T-704	1		Firewater Storage Tank	Flow	1.33	$166,100	1997	$166,100	0.51	$192,175	1.4	$269,045	$274,335
T-709	1		Propane Storage Tank	Flow	1.35	$24,834	2001	$24,834	0.72	$30,825	1.4	$43,155	$42,470
T-710	1		Gasoline Storage Tank	Flow	1.15	$43,500	1997	$43,500	0.51	$46,684	1.4	$65,358	$66,643
T-720	1		CSL Storage Tank	Flow	0.64	$88,100	1997	$88,100	0.79	$61,949	1.4	$86,729	$88,434
T-750	1		Cellulase Storage Tank	Flow	0.74	$125,900	2001	$251,800	0.79	$198,278	1.4	$277,589	$273,186
T-755	1		DAP Storage Bin	Flow	1.06	$33,384	2001	$33,384	0.44	$34,255	1.3	$44,532	$43,826
T-760	1		CSL/DAP Day Tank	Flow	0.93	$30,084	2001	$30,084	0.79	$28,470	1.4	$39,858	$39,226
A700							**Subtotal***	**$1,216,864**		**$1,251,396**	1.6	**$1,975,238**	**$1,956,244**

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Individual Equipment Cost Summary

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H-801	1		Burner Combustion Air Preheater	Heat Duty	0.49	$1,049,900	1997	$1,049,900	0.6	$687,152	1.5	$1,030,728	$1,050,995
H-811	1		BFW Preheater	Area	0.48	$58,400	1997	$58,400	0.68	$35,477	2.1	$74,502	$75,967
M-803	1		Fluidized Bed Combustion Reactor	Flow	0.54	$24,900,000	1998	$24,900,000	0.75	$15,716,316	1.3	$20,431,211	$20,672,504
M-804	1		Combustion Gas Baghouse	Flow	0.55	$2,536,300	1998	$2,536,300	0.58	$1,784,255	1.5	$2,676,383	$2,707,991
M-811	1		Turbine/Generator	Flow	0.66	$10,000,000	1998	$10,000,000	0.71	$7,422,186	1.5	$11,133,279	$11,264,763
M-820	1		Hot Process Water Softener System	Flow	0.77	$1,381,300	1999	$1,381,300	0.82	$1,114,233	1.3	$1,448,503	$1,461,483
M-830	1		Hydrazine Addition Pkg.	Flow	0.83	$19,000	1994	$19,000	0.6	$16,995	1	$16,995	$18,196
M-832	1		Ammonia Addition Pkg	Flow	0.83	$19,000	1994	$19,000	0.6	$16,995	1	$16,995	$18,196
M-834	1		Phosphate Addition Pkg.	Flow	0.83	$19,000	1994	$19,000	0.6	$16,995	1	$16,995	$18,196
P-804	2		Condensate Pump	Flow	1.94	$7,100	1997	$14,200	0.79	$23,987	2.8	$67,162	$68,483
P-811	2		Turbine Condensate Pump	Flow	0.42	$7,800	1997	$15,600	0.79	$7,819	2.8	$21,892	$22,322
P-824	2		Deaerator Feed Pump	Flow	0.59	$9,500	1997	$19,000	0.79	$12,557	2.8	$35,161	$35,852
P-826	5		BFW Pump	Flow	0.34	$52,501	1998	$262,505	0.79	$111,259	2.8	$311,526	$315,205
P-828	2		Blowdown Pump	Flow	0.86	$5,100	1997	$10,200	0.79	$9,089	2.8	$25,448	$25,949
P-830	1		Hydrazine Transfer Pump	Flow	0.83	$5,500	1997	$5,500	0.79	$4,749	2.8	$13,297	$13,559
T-804	1		Condensate Collection Tank	Flow	0.52	$7,100	1997	$7,100	0.71	$4,472	1.4	$6,261	$6,384
T-824	1		Condensate Surge Drum	Flow	0.78	$49,600	1997	$49,600	0.72	$41,541	1.7	$70,619	$72,008
T-826	1		Deaerator	Flow	0.72	$165,000	1998	$165,000	0.72	$129,664	2.8	$363,059	$367,346
T-828	1		Blowdown Flash Drum	Flow	0.87	$9,200	1997	$9,200	0.72	$8,327	2.8	$23,316	$23,775
T-830	1		Hydrazine Drum	Flow	0.83	$12,400	1997	$12,400	0.93	$10,432	1.7	$17,734	$18,083
A800							**Subtotal***	**$40,553,205**		**$27,174,501**	1.4	**$37,801,069**	**$38,257,258**

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Individual Equipment Cost Summary

Equipment Number	Number Required	Number Spares	Equipment Name	Scaled On	Size Ratio (Base/ Current)	Original Equip Cost (per unit)	Base Year	Total Original Equip Cost (Req'd & Spare) in Base Year	Scaling Exponent	Scaled Cost in Base Year	Installation Factor	Installed Cost in Base Year	Installed Cost in 2000$
M-902	1		Cooling Tower System	Heat Duty	0.70	$1,659,000	1998	$1,659,000	0.78	$1,250,136	1.2	$1,500,163	$1,517,880
M-904	2	1	Plant Air Compressor	Flow	1.00	$278,200	2000	$834,600	0.34	$834,598	1.3	$1,084,977	$1,084,977
M-910	1		CIP System	Flow	1.00	$95,000	1995	$95,000	0.6	$95,036	1.2	$114,043	$117,934
P-902	1	1	Cooling Water Pump	Flow	0.67	$332,300	1997	$664,600	0.79	$484,432	2.8	$1,356,409	$1,383,080
P-912	1	1	Make-up Water Pump	Flow	0.76	$10,800	1997	$21,600	0.79	$17,470	2.8	$48,917	$49,879
P-914	2	1	Process Water Circulating Pump	Flow	0.75	$11,100	1997	$33,300	0.79	$26,453	2.8	$74,067	$75,524
S-904	1	1	Instrument Air Dryer	Flow	0.61	$15,498	1999	$30,996	0.6	$23,108	1.3	$30,040	$30,309
T-902	3		Prehydrolysis Filter Air Receiver	Flow	0.89	$17,000	2000	$51,000	0.72	$46,942	1.2	$56,331	$56,331
T-904	1		Plant Air Receiver	Flow	0.61	$13,000	1997	$13,000	0.72	$9,139	1.3	$11,880	$12,114
T-905	4		Product Recovery Filter Air Receiver	Flow	1.04	$17,000	2000	$68,000	0.72	$69,887	1.2	$83,865	$83,865
T-914	1		Process Water Tank	Flow	0.75	$195,500	1997	$195,500	0.51	$168,502	1.4	$235,903	$240,542
A900							**Subtotal***	**$3,666,596**		**$3,025,703**	1.5	**$4,596,596**	**$4,652,435**
						Total Equipment Cost		**$87,764,599**		**$73,987,116**	1.52	**$112,513,533**	**$113,669,816**

*Sections are subtotaled and an average "Installation Factor" is back-calculated for the section.

Appendix C

Chemical Costs and Sources

Chemical Cost and Sources

Raw Material	Cost ($/lb) in 2000 $	Reference
Clarifier Polymer	1.2500	Harris Group, 2000
Sulfuric Acid	0.0124	$25/ton, Chemical Marketing Reporter, 2001
Hydrated Lime	0.0348	$70/ton, Chemical Marketing Reporter, 2001
Corn Steep Liquor	0.0804	Analysis of CSL market, Ruth, M. Report to Process Engineering Team, 5 June 1998
Purchased Cellulase Enzyme	0.0552	Set to $0.10/gal ethanol, based on purchased, delivered enzyme
Diammonium Phosphate	0.0706	$142/ton, Chemical Marketing Reporter, 2001
Propane	0.0022	$0.734/gal, 1999 average from DOE Energy Information Administration
Makeup Water	0.0001	$1/1000 gal, Middle of range $0.35-$1.50/1000 gal in Peters/Timmerhaus, pg. 815
Boiler Chemicals	1.3497	Radian Report, Cases
Cooing Tower Chems	1.0204	Unknown
WasteWater Chems	0.1579	Merrick Report Appendix G
WasteWater Polymer	2.5510	Merrick Report Appendix G
Gasoline Denaturant	0.0967	$0.555/gal, Analysis of Corn ethanol producers' cost, 1999 average
Utility		
Solid Disposal	0.0094	$20/ton, Chem Systems Report 1993
Co-product credit		
Electricity	$0.041/kWh	Chem Systems Report, 1994

Appendix D

Discounted Cash Flow Rate of Return Summary

Year		-2	-1	0	1	2	3	4	5	6	7	8	9	10
Fixed Capital Investment		$15,794,024	$118,455,184	$63,176,098										
Working Capital				$9,871,265										
Ethanol Sales					$55,407,468	$73,876,624	$73,876,624	$73,876,624	$73,876,624	$73,876,624	$73,876,624	$73,876,624	$73,876,624	$73,876,624
By-Product Credit					$4,824,203	$6,432,270	$6,432,270	$6,432,270	$6,432,270	$6,432,270	$6,432,270	$6,432,270	$6,432,270	$6,432,270
Total Annual Sales					$60,231,670	$80,308,894	$80,308,894	$80,308,894	$80,308,894	$80,308,894	$80,308,894	$80,308,894	$80,308,894	$80,308,894
Annual Manufacturing Cost														
Raw Materials					$20,272,908	$23,169,038	$23,169,038	$23,169,038	$23,169,038	$23,169,038	$23,169,038	$23,169,038	$23,169,038	$23,169,038
Ion Exchange Resin					$0					$0				
Baghouse Bags					$349,682					$349,682				
Other Variable Costs					$12,932,287	$14,779,757	$14,779,757	$14,779,757	$14,779,757	$14,779,757	$14,779,757	$14,779,757	$14,779,757	$14,779,757
Fixed Operating Costs					$7,540,360	$7,540,360	$7,540,360	$7,540,360	$7,540,360	$7,540,360	$7,540,360	$7,540,360	$7,540,360	$7,540,360
Total Product Cost					$41,095,237	$45,489,155	$45,489,155	$45,489,155	$45,489,155	$45,838,837	$45,489,155	$45,489,155	$45,489,155	$45,489,155
Annual Depreciation														
General Plant														
DDB					$37,422,543	$26,730,388	$19,093,134	$13,637,953	$9,741,395	$6,958,139	$4,970,099			
SL					$18,711,271	$15,592,726	$13,365,194	$11,933,209	$11,364,961	$11,364,961	$11,364,961			
Remaining Value					$93,556,357	$66,825,969	$47,732,835	$34,094,882	$24,353,487	$17,395,348	$12,425,249			
Actual					$37,422,543	$26,730,388	$19,093,134	$13,637,953	$11,364,961	$11,364,961	$11,364,961			
Steam Plant														
DDB					$4,983,480	$4,609,719	$4,263,990	$3,944,191	$3,648,377	$3,374,749	$3,121,642	$2,887,519	$2,670,955	$2,470,634
SL					$3,322,320	$3,234,891	$3,158,511	$3,093,483	$3,040,314	$2,999,777	$2,972,993	$2,961,558	$2,961,558	$2,961,558
Remaining Value					$61,462,926	$56,853,206	$52,589,216	$48,645,025	$44,996,648	$41,621,899	$38,500,257	$35,612,738	$32,941,782	$30,471,149
Actual					$4,983,480	$4,609,719	$4,263,990	$3,944,191	$3,648,377	$3,374,749	$3,121,642	$2,961,558	$2,961,558	$2,961,558
Net Revenue					($23,269,590)	$3,479,632	$11,462,614	$17,237,595	$19,806,401	$19,730,348	$20,333,136	$31,858,181	$31,858,181	$31,858,181
Losses Forward						($23,269,590)	($19,789,958)	($8,327,344)	$0	$0	$0	$0	$0	$0
Taxable Income					($23,269,590)	($19,789,958)	($8,327,344)	$8,910,250	$19,806,401	$19,730,348	$20,333,136	$31,858,181	$31,858,181	$31,858,181
Income Tax					$0	$0	$0	$3,474,998	$7,724,496	$7,694,836	$7,929,923	$12,424,690	$12,424,690	$12,424,690
Annual Cash Income					$19,136,433	$34,819,739	$34,819,739	$31,344,741	$27,095,242	$26,775,222	$26,889,816	$22,395,048	$22,395,048	$22,395,048
Discount Factor		1.21	1.1	1	0.909090909	0.826446281	0.751314801	0.683013455	0.620921323	0.56447393	0.513158118	0.46650738	0.424097618	0.385543289
Annual Present Value	$220,991,534				$17,396,757	$28,776,644	$26,160,585	$21,408,880	$16,824,014	$15,113,915	$13,798,727	$10,447,455	$9,497,687	$8,634,261
Total Capital Investment + Interest		$19,110,770	$130,300,702	$73,047,363										
Net Present Worth				$0										

If income taxable income < 0, tax = $0
Loan Interest subtracted from taxable income.
Loan payment subtracted from annual cash income
Interest on construction loan added to investment

NPV of Income Tax	$60,794,932				$0	$0	$0	$2,373,470	$4,796,305	$4,343,534	$4,069,304	$5,796,210	$5,269,282	$4,790,256
NPV of Ethanol Income	$612,163,202				$50,370,425	$61,055,061	$55,504,601	$50,458,728	$45,871,571	$41,701,428	$37,910,389	$34,463,990	$31,330,900	$28,482,637

Year	11	12	13	14	15	16	17	18	19	20
Fixed Capital Investment										
Working Capital										($9,871,265)
Ethanol Sales	$73,876,624	$73,876,624	$73,876,624	$73,876,624	$73,876,624	$73,876,624	$73,876,624	$73,876,624	$73,876,624	$73,876,624
By-Product Credit	$6,432,270	$6,432,270	$6,432,270	$6,432,270	$6,432,270	$6,432,270	$6,432,270	$6,432,270	$6,432,270	$6,432,270
Total Annual Sales	$80,308,894	$80,308,894	$80,308,894	$80,308,894	$80,308,894	$80,308,894	$80,308,894	$80,308,894	$80,308,894	$80,308,894
Annual Manufacturing Cost										
Raw Materials	$23,169,038	$23,169,038	$23,169,038	$23,169,038	$23,169,038	$23,169,038	$23,169,038	$23,169,038	$23,169,038	$23,169,038
Ion Exchange Resin	$0					$0				
Baghouse Bags	$349,682					$349,682				
Other Variable Costs	$14,779,757	$14,779,757	$14,779,757	$14,779,757	$14,779,757	$14,779,757	$14,779,757	$14,779,757	$14,779,757	$14,779,757
Fixed Operating Costs	$7,540,360	$7,540,360	$7,540,360	$7,540,360	$7,540,360	$7,540,360	$7,540,360	$7,540,360	$7,540,360	$7,540,360
Total Product Cost	$45,838,837	$45,489,155	$45,489,155	$45,489,155	$45,489,155	$45,838,837	$45,489,155	$45,489,155	$45,489,155	$45,489,155
Annual Depreciation										
General Plant										
DDB										
SL										
Remaining Value										
Actual										
Steam Plant										
DDB	$2,285,336	$2,113,936	$1,955,391	$1,808,736	$1,673,081	$1,547,600	$1,431,530	$1,324,165	$1,224,853	$1,132,989
SL	$2,961,558	$2,961,558	$2,961,558	$2,961,558	$2,961,558	$2,961,558	$2,961,558	$2,961,558	$2,961,558	$2,961,558
Remaining Value	$28,185,812	$26,071,877	$24,116,486	$22,307,749	$20,634,668	$19,087,068	$17,655,538	$16,331,373	$15,106,520	$13,973,531
Actual	$2,961,558	$2,961,558	$2,961,558	$2,961,558	$2,961,558	$2,961,558	$2,961,558	$2,961,558	$2,961,558	$2,961,558
Net Revenue	$31,508,499	$31,858,181	$31,858,181	$31,858,181	$31,858,181	$31,508,499	$31,858,181	$31,858,181	$31,858,181	$31,858,181
Losses Forward	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Taxable Income	$31,508,499	$31,858,181	$31,858,181	$31,858,181	$31,858,181	$31,508,499	$31,858,181	$31,858,181	$31,858,181	$31,858,181
Income Tax	$12,288,315	$12,424,690	$12,424,690	$12,424,690	$12,424,690	$12,288,315	$12,424,690	$12,424,690	$12,424,690	$12,424,690
Annual Cash Income	$22,181,743	$22,395,048	$22,395,048	$22,395,048	$22,395,048	$22,181,743	$22,395,048	$22,395,048	$22,395,048	$22,395,048
Discount Factor	0.350493899	0.318630818	0.28966438	0.263331254	0.239392049	0.217629136	0.197844669	0.17985879	0.163507991	0.148643628
Annual Present Value	$7,774,565	$7,135,753	$6,487,048	$5,897,316	$5,361,197	$4,827,393	$4,430,741	$4,027,946	$3,661,769	$3,328,881
Total Capital Investment + Interest										($1,467,301)
Net Present Worth										
NPV of Income Tax	$4,306,979	$3,958,889	$3,598,990	$3,271,809	$2,974,372	$2,674,295	$2,458,159	$2,234,690	$2,031,536	$1,846,851
NPV of Ethanol Income	$25,893,306	$23,539,369	$21,399,426	$19,454,024	$17,685,476	$16,077,706	$14,616,096	$13,287,360	$12,079,418	$10,981,289

Ethanol Production Process Engineering Analysis

Corn Stover Design Report Case, process P110: 2010 plant start-up
Dilute Acid Prehydrolysis with Saccharification and Co-Fermentation
All Values in 2000$

Minimum Ethanol Selling Price **$1.07**

Ethanol Production (MM Gal. / Year)	69.3	Ethanol at 68°F
Ethanol Yield (Gal / Dry US Ton Feedstock)	89.7	
Feedstock Cost $/Dry US Ton	$30	
Internal Rate of Return (After-Tax)	10%	
Equity Percent of Total Investment	100%	

Capital Costs	
Feed Handling	$7,500,000
Pretreatment	$19,000,000
Neutralization/Conditioning	$7,800,000
Saccharification & Fermentation	$9,400,000
Distillation and Solids Recovery	$21,800,000
Wastewater Treatment	$3,300,000
Storage	$2,000,000
Boiler/Turbogenerator	$38,300,000
Utilities	$4,700,000
Total Installed Equipment Cost	$113,700,000
Added Costs	$83,700,000
(% of TPI)	42%
Total Project Investment	$197,400,000
Loan Rate	N/A
Term (years)	N/A
Capital Charge Factor	0.176
Denatured Fuel Prod. (MMgal / yr)	72.5
Denatured Fuel Min. Sales Price	$1.04
Denaturant Cost ($/gal denaturant)	$0.555
Maximum Yields (100% of Theoretical)	
Ethanol Production (MM Gal/yr)	87.0
Theoretical Yield (Gal/ton)	112.7
Current Yield (Actual/Theoretical)	80%

Operating Costs (cents/gal ethanol)	
Feedstock	33.4
Biomass to Boiler	0.0
CSL	2.8
Cellulase	10.1
Other Raw Materials	5.5
Waste Disposal	2.9
Electricity	-9.3
Fixed Costs	10.9
Capital Depreciation	14.3
Average Income Tax	10.6
Average Return on Investment	25.4
	106.8

Operating Costs ($/yr)	
Feedstock	$23,200,000
Biomass to Boiler	$0
CSL	$1,900,000
Cellulase	$7,000,000
Other Raw Matl. Costs	$3,800,000
Waste Disposal	$2,000,000
Electricity	-$6,400,000
Fixed Costs	$7,500,000
Capital Depreciation	$9,900,000
Average Income Tax	$7,300,000
Average Return on Investment	$17,600,000
	$73,800,000
Excess Electricity (KWH/gal)	2.28
Plant Electricity Use (KWH/gal)	1.42
Plant Steam Use (kg steam/gal)	16.7
Boiler Feed -- LHV (Btu/lb)	2,870
Boiler Feed -- Water Fraction	0.518

Production Rate (MM gal/yr)	69.27	24,686	Feedstock Dry Tons/yr	772168							
			gal/ton	90							
Hours per Year	8,406										
Variable Operating Costs											
Costing Code	**Raw Material**	**Stream No.**	**kg/hr**	**lb/hr**	**Quoted Price (cents / ton)**	**Year of Price Quote**	**2000 Cost (cents / ton)**	**2000 Cost ($/lb)**	**$/hour**	**MM$/yr (2000)**	**Cents/Gallon Ethanol (2000)**
F-1	Feedstock	STRM010	98,039	216,176	2550	2000	2550.00	0.0128	2756.25	23.17	33.45
F-1	Feedstock	STRM084	0	0	2550	2000	2550.00	0.0128	0.00	0.00	0.00
S-11	Clarifier Polymer	STRM010	28	63	250000	2000	250000.00	1.2500	78.24	0.66	0.95
R-5	Sulfuric Acid	STRM071	3,288	7,251	2500	2001	2485.99	0.0124	90.13	0.76	1.09
R-4	Hydrated Lime	STRM074	2,395	5,280	7000	2001	6960.77	0.0348	183.77	1.54	2.23
R-3	Corn Steep Liquor	STRM073	1,306	2,879	15000	1998	16087.17	0.0804	231.57	1.95	2.81
R-7	Purchased Cellulase	STRM075	6,824	15,046	10823	1999	11044.07	0.0552	830.86	6.98	10.08
R-8	Ammonium Phosphate	STRM075	163	360	14200	2001	14120.42	0.0706	25.42	0.21	0.31
S-12	Propane	3	20	45	436	1999	444.90	0.0022	0.10	0.00	0.001
S-8	Makeup Water	STRM090	189,649	411,562	24	1990	23.30	0.0001	48.67	0.40	0.58
S-1	Boiler Chemicals	STRM092	1.0	2	280000	1991	269932.90	1.3497	2.98	0.03	0.04
S-2	Cooling Tower Chems	STRM092	1.9	4	200000	1999	204081.02	1.0204	4.28	0.04	0.05
S-4	WasteWater Chems	STRM063	57.9	128	30956	1999	31587.66	0.1579	20.18	0.17	0.24
S-5	WasteWater Polymer	STRM063	0.2	0.43	500000	1999	510202.54	2.5510	1.10	0.01	0.01
	Subtotal								**4272.73**	**35.92**	**51.85**
	Waste Streams										
W-2	Disposal of Steam 809	STRM080	4,492	9,906	1820	1993	1872.61	0.0094	92.75	0.78	1.13
W-3	Disposal of Stream 229	STRM022	7,217	15,913	1820	1993	1872.61	0.0094	148.99	1.25	1.81
	Subtotal								**241.74**	**2.03**	**2.93**
	By-Product Credits		KW		$/KW			**$/kWh**			
P-1	Electricity	WKNET	18,747	na	0.040	1999		0.041	765.20	6.43	9.29
	Subtotal								**765.20**	**6.43**	**9.29**
	Total Variable Operating Costs								**3,749.29**	**31.52**	**45.50**
	Fixed Operating Costs										
	Plant Manager	80000	1	80,000							
	Plant Engineer	65000	1	65,000							
	Maintenance Supr	60000	1	60,000							
	Lab Manager	50000	1	50,000							
	Shift Supervisor	37000	5	185,000							
	Lab Technician	25000	2	50,000							
	Maintenance Tech	28000	8	224,000							
	Shift Operators	25000	20	500,001							
	Yard Employees	20000	32	640,001							
	General Manager	100000	1	100,000							
	Clerks & Secretaries	20000	5	100,000							
	Total Salaries			2,054,002						2.15	3.11
	Overhead/Maint	60%	of Labor & Supervison	1,292,976						1.29	1.87
	Maintenance	2%	Equipment Cost	2,273,396						2.27	3.28
	Insurance & Taxes	1.5%	of Total Installed Cost	1,819,029						1.82	2.63
	Total Fixed Operating Costs									**7.54**	**10.89**
	Total Cash Cost									**39.06**	**56.38**

Appendix E

Process Parameters

Process Area	Process Parameter	Model Value
	Minimum Ethanol Selling Price ($/gal)	$1.07
Feedstock	Feedstock Flow (dry metric ton/day)	2000
	Feedstock Cost ($/dry US ton)	$30
	Cellulose Fraction	37.4%
	Xylan Fraction	21.1%
	Arabinan Fraction	2.9%
	Mannan Fraction	1.6%
	Galactan Fraction	2.0%
	Lignin Fraction	18.0%
Pretreatment	Reactor Residence Time	2 min
	Acid Concentration	1.1%
	Temperature	190°C
	Xylan to Xylose Yield	90%
	Mannan to Mannose Yield	90%
	Galactan to Galactose Yield	90%
	Arabinan to Arabinose Yield	90%
	Type of Conditioning	Overliming
Saccharification	Cellulase Purchase Price ($/gal total ethanol)	$0.10
	Cellulase Purchase Price ($/gal cellulose-derived ethanol)	$0.17
	Residence Time	1.5 days
	Temperature	65°C
	Cellulose to Glucose Yield	90%
Co-Fermentation	Residence Time	1.5 days
	Temperature	41°C
	Glucose to Ethanol Yield	95%
	Xylose to Ethanol Yield	85%
	Arabinose to Ethanol Yield	85%
	Mannose to Ethanol Yield	85%
	Galactose to Ethanol Yield	85%
	Contamination Loss	3%
	Overall Cellulose to Ethanol Yield	85.5%
Utilities	Electricity Credit ($/kWh)	$0.041
	On-line Time (hr/yr)	8406
Model: I0203I		

Appendix G

Changes from the 1999 Design Report

The following section describes the major changes that have been made since the 1999 design report. In general, the process changes came from a new feedstock, better design and cost information, the need to portray the current state of research in enzyme production, and the change to target yields for pretreatment and co-fermentation that can be achieved in the next several years. Other minor changes (to the mass and energy balance model) had a small combined cost effect.

Corn Stover Feedstock

The change in feedstock from yellow poplar hardwood chips to corn stover is a major one. There are fewer carbohydrates in corn stover than hardwood, so the theoretical of ethanol yield per ton of feedstock is lower. The feedstock cost of $30 per dry short ton is an increase from wood chips at $25 per dry short ton. The cost represents our current understanding of the expected harvesting capabilities, transportation and farmer costs required to obtain stover in 2010. ORNL has been instrumental in providing us with information on feedstock costs to use in the process model, and continues to work towards a better understanding of the availability and cost of stover.

It is assumed that the bales would be stored in several locations until needed. The cost of offsite storage for the once-per-year harvest of stover was not included in this design.

The change from a loose, piled feedstock like wood chips to baled stover presented several changes in the feedstock receiving and handling area, including moving the bales, breaking them up, and making the stalks and other long pieces small enough to feed to the pretreatment reactors. Corn stover also contains a higher percentage of dirt and less moisture than wood chips, so dust and debris were issues. The Harris group looked at several designs for moving, unbaling, washing, and shredding baled corn stover, and picked one based on its performance in existing similar applications. The total installed cost of $7.5MM for stover handling equipment was $2.6MM higher than that for wood chips. The stover handling equipment was also sized on a dry feed rate unlike the wood chip handling equipment, which was sized on a total feed rate basis. It is conceivable that this system is overdone, and the washing and size reduction could be reduced as we learn to handle or minimize the dirt picked up in harvesting and gain a better understanding of the effect of particle size.

Labor for the baled feedstock was a significant change - eight forklift operators per shift for corn stover versus two bulldozer drivers for chips. Because the bales are trucked in and must be unloaded, a substantial amount of bale moving is anticipated.

Pretreatment Reactor and Yields

The Harris Group contacted several vendors for design and cost information to augment the information we obtained from Sunds through Delta-T. Anco-Eaglin and Andritz provided detailed estimates. Both companies specified lower cost metallurgy for the wetted parts (Incoloy 825 clad steel and Incoloy 825, respectively) than Sunds originally did (Hastelloy C-2000) for the pretreatment conditions. Harris contracted with a corrosion lab and corrosion consultant to conduct testing on these materials. The lower cost of the Anco-Eaglin system provided a savings of about $5.5MM in purchased and $2.5MM in installed equipment cost over the Sunds unit. The reason for this decrease in savings as the installation factor is applied is that the Anco-Eaglin system has a larger installation factor of 2.29 versus a factor of 1.5 for the Sunds unit. Yield targets were increased from 75 to 90% for hemicellulose to monomer conversion.

Solid-Liquid Separation Equipment

A significant portion of the Harris Group's work was with solid-liquid separation vendors in an attempt to optimize the design of equipment for both separation of prehydrolyzate slurry and post-distillate slurry. As a result of vendor testing over a wide range of separator types, a Pneumapress pressure filter was chosen for the prehydrolyzate slurry application based on its performance in solid recovery, cake dryness, and washing ability. When compared against the other quotes (for horizontal belt filters), the Pneumapress filter's estimated installed cost was $2.2MM more than the closest cost quote, but $18.5MM less than the highest quote. However, its separation and washing efficiencies were superior to the horizontal belt filters. The installed cost of the Pneumapress system was about $4MM higher than our current estimate for a belt filter press ($6.3MM installed cost for the Pneumapress and peripherals compared to $2.1MM for the belt filter press), however, it allows for washing with a minimal amount of liquid, and has been verified through vendor testing.

For the post-distillate solids, the Pneumapress system used here is again about $4MM more expensive than the prior centrifuge cost ($6.4MM versus $2.4MM), but also allows the removal of the solids dryer ($2.2MM). The flue gas, previously used for drying, can now be used in a combustion air preheater ($1.1MM). Also, Harris' estimated installed cost for a centrifuge system in this application (including all extraneous equipment such as pumps, conveyors, etc.) was $0.7MM more expensive than that of the Pneumapress system. Because this data was based on vendor tests, we consider it more reliable than the previous separation equipment costs used

Enzymatic Hydrolysis (Saccharification) and Co-Fermentation

Based on our current understanding of what production of the first commercially available enzyme preparation for lignocellulosic biomass will entail, a cost of $0.10 per gallon of ethanol was used for enzyme delivered to the plant from a local enzyme facility. This is a major change from the previous design, which assumed on-site fermentation of the enzyme using *T. Reesei* fungi (previously Area 400 in the design). The installed capital ($15.5MM) and operating costs associated with that production were about $0.30 per gallon ethanol. The electrical demand of the plant is roughly halved without the enzyme production fermenters. Chilled water demand is also greatly reduced by removing cellulase production.

In preparation for an improved thermal tolerant enzyme, the SSCF process was separated into separate saccharification and co-fermentation. The saccharification yield target was increased and the fermentation yield target for glucose was also increased.

Other Changes

1. Distillation column costing

Both the beer column and rectification distillation column capital costs are now scaled by the square of the diameter (previously just the diameter), to better represent the size (and hence cost) by a variable that is proportional to cross-sectional flow.

2. Solids Dryer Testing

In the current design, the solids fed to the boiler are not being dried, due to the high efficiency of the Pneumapress unit. The previous design used a centrifuge, and required a dryer to get the total boiler feed moisture content low enough to support combustion. A rotary drum dryer, similar to those used to dry the Distiller's Dried Grains (DDG) in the corn ethanol industry was used with

the hot flue gas as the heat source. The cost of the dryer was about $2.2MM, and was incorporated into the design (replacing the rotary drum dryer) until the Pneumapress unit replaced it and the centrifuge in this new design.

Summary of Significant Changes

	1999 Design Report	2002 Design Report	Ethanol Selling Price ($/gal)
1999 Reported Cost (Model: R9906A, 1997 $)			$1.44
Feedstock	Hardwood Chips	Corn Stover	+$0.06
Feedstock Cost	$25 per dry ton	$30 per dry ton	+$0.07
Feedstock Handling Installed Cost	$4.9MM	$7.5MM	+$0.02
Feedstock Handling Labor	2 per shift	8 per shift	+0.02
Pretreatment Reactor	Hastelloy C-2000	Incoloy 825 clad steel	-$0.01
Pretreatment Targets and Conditions	75% Hemicellulose to Monomer Yield 190°C 0.5% acid, 10 minutes	90% Hemicellulose to Monomer Yield 190°C, 1.1% acid, 2 minutes	-$0.06
Conditioning	Ion exchange and overliming	Overliming only	-$0.08
Solid-Liquid Separation Equipment	Belt Filter Press/Centrifuge	Pneumapress Pressure Filters	+$0.01
Enzyme	Produced on-site for $0.30 per gallon ethanol	Purchased for $0.10 per gallon ethanol	-$0.20
Enzymatic Hydrolysis and Fermentation Configuration	SSCF	Saccharification and Co-Fermentation	-$0.01
Fermentation Targets	73.6% Cellulose to Ethanol Yield	85.5% Cellulose to Ethanol Yield	-$0.15
	85% Xylose to Ethanol Yield	85% all Hemicelluosic Sugars to Ethanol Yield	-$0.10
Cost Year Change	1997	2000	+$0.04
Other Minor Model Fixes			+$0.02
2002 Reported Cost (Model: I0203I, 2000 $			$1.07

Appendix H

Chemical Formulas for Biomass Compounds

Chemical Formulas for Biomass Compounds

Compound Name	Chemical Formula	Notes
Acetate	$C_2H_4O_2$	
Arabinan	$C_5H_8O_4$	Use Xylan Properties
Arabinose	$C_5H_{10}O_5$	Use Xylose properties
Cellobiose	$C_{12}H_{22}O_{11}$	Use Glucose properties
Cellulose	$C_5H_{10}O_5$	
Corn Steep Liquor (CSL)	Unknown	Modeled as water
Furfural	$C_5H_4O_2$	
Galactan	$C_6H_{10}O_5$	Use Cellulose properties
Galactose	$C_6H_{12}O_6$	Use Glucose properties
Glucose	$C_6H_{12}O_6$	
HydroxyMethylFurfural (HMF)	$C_5H_4O_2$	Use Furfural properties
Lignin	$C_{10}H_{13.9}O_{1.3}$	
Mannan	$C_6H_{10}O_5$	Use Cellulose properties
Mannose	$C_6H_{12}O_6$	Use Glucose properties
Soluble Lignin	$C_{10}H_{13.9}O_{1.3}$	Use Glucose properties for liquid-liquid interactions
Tar	$C_5H_8O_4$	Use Xylan Properties
Xylan	$C_5H_8O_4$	
Xylose	$C_5H_{10}O_5$	
Z. mobilis	$CH_{1.8}O_{0.5}N_{0.2}$	

Appendix I

Physical Property Model and Parameters for Distillation

Physical property models and parameters are important throughout a rigorous mass and energy balance model such as the one used here. This is even truer for distillation calculations involving azeotropes such as the separation of ethanol from water. The physical property option[i] selected for this ASPEN model uses the NRTL[ii] activity coefficient (g_i) model for the liquid phase fugacity, f_i , calculation. The vapor phase is modeled using the ideal gas law, which makes the vapor fugacity coefficient equal to one. The vapor phase fugacity coefficient is not nearly as important as the liquid phase fugacity because of the low-pressure operation.

The liquid phase equation for liquid fugacity is:

$$f_i = x_i g_i f_i^{*,}$$

The pure component liquid fugacity, $f_i^{*,}$, reduces to the pure component vapor pressure, $p_i^{*,}$, at low pressures (the Poynting correction is unity). The NRTL activity coefficient model and vapor pressure models used by ASPEN are given below. Tables 11 and 12 give the ethanol and water parameters for those equations.

$$\ln g_i = \frac{\sum_j x_j t_{ji} G_{ji}}{\sum_k x_k G_{ki}} + \sum_j \left(\frac{x_j G_{ij}}{\sum_k x_k G_{kj}} t_{ij} - \frac{\sum_m x_m t_{mj} G_{mj}}{\sum_k x_k G_{kj}} \right)$$

Where:

$$G_{ij} = \exp(-a_{ij} t_{ij})$$

$$t_{ij} = a_{ij} + b_{ij}/T + e_{ij} \ln T + f_{ij} T$$

$$a_{ij} = c_{ij} + d_{ij}(T - 273.15)$$

$$t_{ii} = 0$$

$$G_{ii} = 1$$

$$a_{ij} = a_{ji}$$

$$b_{ij} = b_{ji}$$

$$c_{ij} = c_{ji}$$

$$d_{ij} = d_{ji}$$

Vapor Pressure Correlation

$$\ln p_i^{*,} = C_{1i} + \frac{C_{2i}}{T + C_{3i}} + C_{4i} T + C_{5i} \ln T + C_{6i} T^{C_{7i}}$$

NRTL Activity Coefficient Model Parameters [iii]

aij	0
aji	0
bij	-55.1698
bji	670.4442
cij	0.3031
dij	0
eij	0
eji	0
fij	0
fji	0
Lower Temperature Limit	348.15
Upper Temperature Limit	373.15
Note: i – ethanol, j – water	

Vapor Pressure Model Parameters [iii]

Eq. Parameters	**Ethanol**	**Water**
C1	74.475	73.649
C2	-7164.3	-7258.2
C3	0	0
C4	0	0
C5	-7.3270	-7.3037
C6	3.1340E-06	4.1653E-06
C7	2	2
Lower Temperature Limit	159.05	273.16
Upper Temperature Limit	513.92	647.13
Temperature Units, Kelvins Pressure Units, Pascals		

[i] "ASPEN Plus™, Reference Manual–Volume 2, Physical Property Methods and Models," Release 9.3, Aspen Technology, Inc., Cambridge, MA, 1996.

[ii] Renon, H., and J.M. Praustniz, "Local Composition in Thermodynamic Excess Functions for Liquid Mixtures,"*AIChE J*., 14(1), 135, 1968.

[iii] "ASPEN Plus™, Reference Manual–Volume 3, Physical Property Data,"Release 9.3, Aspen Technology, Inc., Cambridge, MA, 1996.

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