*Energy and Environmental Science*

# An Optimization-Based Assessment Framework for Biomass-to-Fuels Conversion Strategies

## Electronic Supplementary Information

*Jiyong Kim, S. Murat Sen and Christos T. Maravelias*[*]

Department of Chemical and Biological Engineering
University of Wisconsin – Madison, WI 53706.

[*] Corresponding author: Tel.: +1 608 265 9026; Fax: +1 608 262 5494. E-mail address: maravelias@wisc.edu

# A. Parameter evaluation examples

## Example: Ethanol from corn stover via biochemical conversion

## A1. Data extraction from literature

- Literature sources: NREL 2007 [21] (economic data); NREL 2002 [22] (stream data).
- Capacity and reference year: 53 Mgal of ethanol/year (19,040 kg/h) and 2007
- The system consists of eight main sections (See Figure S1);
  - Feed handling (including shredding and washing)
  - Pretreatment (including prehydrolysis, overliming and neutralization)
  - Saccharification and fermentation (including seed fermentation)
  - Distillation and solid recovery (including evaporation and S/L separation)
  - Wastewater treatment
  - Storage system
  - Boiler & turbogenerator
  - Utilities supply

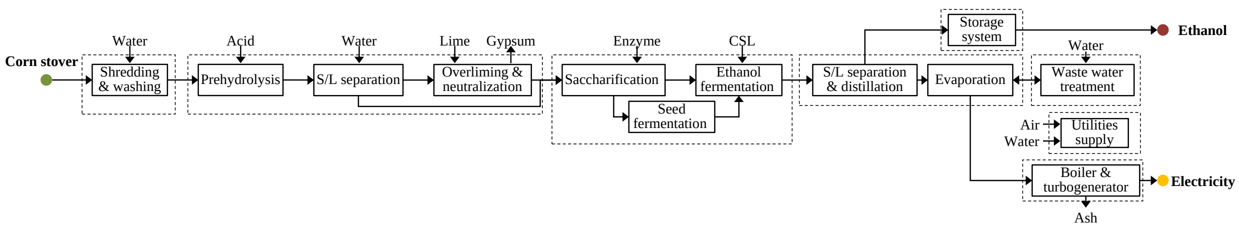



**Fig. S1.** Overall flowsheet of an ethanol production system from corn stover via biochemical conversion; dotted boxes represent the main sections.

### Capital cost and major material and energy consumption data

**Table S1.** Capital cost of main sections [M$].

| | Equipment cost | Total capital cost |
|---|---|---|
| Feed handling | 10.9 | 25.0 |
| Pretreatment | 36.2 | 82.9 |
| Saccharification & fermentation | 21.8 | 49.9 |
| Distillation & solids recovery | 26.1 | 59.8 |
| Wastewater treatment | 3.5 | 8.0 |
| Storage | 3.2 | 7.3 |
| Boiler & turbogenerator | 56.1 | 128.5 |
| Utilities supply | 6.3 | 14.4 |
| Total | 164.1 | 375.9 |

**Table S2.** Materials and energy consumption data

| | Materials (ton/hr) | Heat (MW)[1] | Electricity (MW) |
|---|---|---|---|
| Feed handling | Sulfuric acid (3.7) | - | 1.6 |
| Pretreatment | Lime (6.1) | 32.0 | 1.8 |
| Saccharification & fermentation | CSL (4.5), Enzyme (8.7) | 4.1 | 1.8 |
| Distillation and solids recovery | | 45.0 | 1.4 |
| Wastewater treatment | Makeup water (186.6) | 0.9 | 0.5 |
| Storage | | - | <0.1 |
| Boiler & turbogenerator | | 2.1 | 1.1 |
| Utilities supply | | - | 3.6 |
| Total | | 84.2 | 11.7 |

[1] CSL: Corn steep liquor. [2] Low pressure (LP) steam is assumed except pretreatment where a part of heat (29.3MW) is from high pressure (HP) steam.

Major component conversion rates:

- Pretreatment: cellulose → sugars (0.01); hemicellulose → sugars (0.91); lignin → sugars (0.04)
- In saccharification: cellulose → sugars (0.88)
- In fermentation: sugars → ethanol (0.4)

Waste streams and byproduct data

- Gypsum: 13.8 ton/hr
- Ash: 12.4 ton/hr
- Electricity: 24,756 kW

## A2. System division into technologies and compounds

We breakdown the system (eight sections) into four technologies as shown in Figure S2.

- ***DA pretreatment*** (including *Feed handling* and *Pretreatment*)
- ***SSF*** (*Saccharification and fermentation*)
- ***Distillation-E*** (including *Distillation and solid recovery*, *Wastewater treatment* and *Storage*)
- ***CHP*** (*Boiler & turbogenerator*)

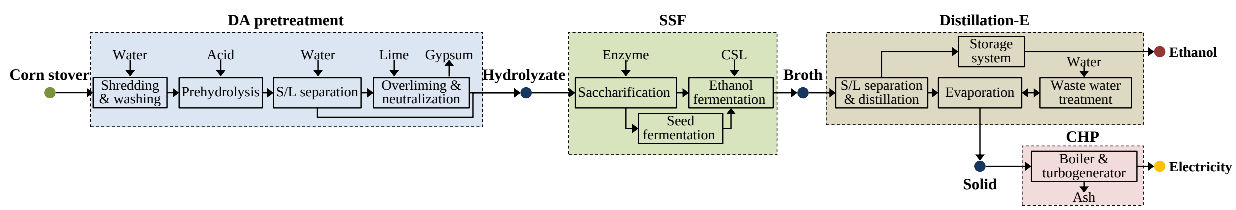



**Fig. S2.** The technologies in the ethanol production from corn stover strategy.

Accordingly five compounds (*Corn stover*, *Hydrolyzate*, *Broth*, *Solid and Ethanol*) and *Electricity* as byproduct were considered.

**Table S3.** Flow rate and major components of the compounds[1]

| | Corn stover | Hydrolyzate | Broth | Ethanol | Solid | Electricity |
|---|---|---|---|---|---|---|
| Total flow (kg/h) | 111,125 | 416,125 | 429,208 | 19,042 | 46,355 | 24,756[2] |
| Major compounds (kg/h) | | | | | | |
| Cellulose | 31,187 | 28,567 | - | - | - | - |
| Hemicellulose | 22,924 | 573 | - | - | - | - |
| Lignin | 15,002 | 14,251 | - | - | - | - |
| Sugars | - | 21,773 | - | - | - | - |
| Ethanol | - | - | 18,882 | 18,946 | - | - |
| Water | 27,792 | 292,677 | 342,400 | 95 | 3,620 | - |
| Others | 14,220 | 58,284 | 67,926 | - | 42,735 | - |
| Electricity (kW) | - | - | - | - | - | 24,756 |

[1] Only main components (e.g., cellulose, hemicellulose, sugar and ethanol) of the main stream (i.e., reactant and product) are used for yield estimation, but other auxiliary inputs (e.g., acids and enzymes) are taken into account as operation expenses (i.e., variable operating cost).

[2] Unit: kW. This is the net amount of electricity which goes out of the plant, *excess electricity*. Beside this excess electricity, technology *CHP* produces steam (84,176 MW) and electricity (11,717 kW) which are used in the plant.

## A3. Parameter evaluation

Capital cost calculation:

- Capacity factor: 98% (8,600 on-stream hours/year).
- The capacity and time-value adjustments are not applied here, since the capacity and reference year are same with baseline of this study.
- The cost for the utilities supply system is distributed to four technologies in proportion to their capital costs.

**Table S4.** Capital cost of technologies.

| | Equipment cost (M$) | Total capital cost (M$) |
|---|---|---|
| DA pretreatment | 49.0 | 112.2 |
| SSF | 22.7 | 51.9 |
| Distillation-E | 34.1 | 78.1 |
| CHP | 58.3 | 133.6 |
| Total | 164.1 | 375.9 |

Energy consumption calculation:

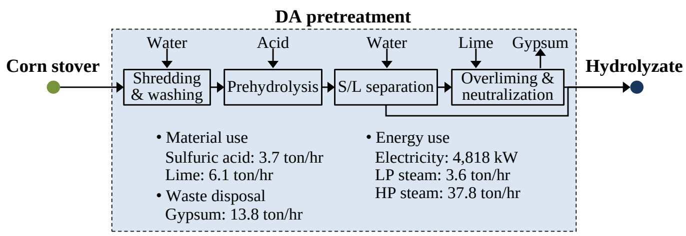
- The heating value steam: 0.78 kWh/kg (HP steam) and 0.75 kWh/kg (LP steam).
- The electricity consumed in the utilities supply system is distributed to four technologies in proportion to their electricity consumptions.

**Table S5.** Energy consumption of technologies [MW].

| | Steam | Electricity | Total |
|---|---|---|---|
| DA pretreatment | 32.0 | 4.8 | 36.8 |
| SSF | 4.1 | 2.6 | 6.8 |
| Distillation-E | 46.0 | 2.7 | 48.7 |
| CHP | 2.1 | 1.6 | 3.6 |
| Total | 84.2 | 11.7 | 95.9 |

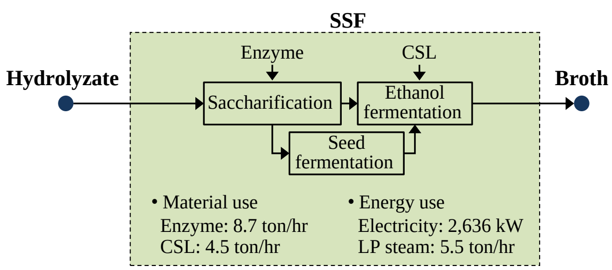
Annual cost calculation:

- Capital charge factor: 0.1175
- Material and energy price and waste disposal cost
  Sulfuric acid, lime, CSL, enzyme and water price: 33.2, 93.1, 215, 507 and 1 $/ton, respectively.
  Electricity price: 0.06 $/kWh
  HP steam and LP steam price: 14.5 and 10.5 $/ton
  Gypsum and ash disposal cost: 29.6 $/ton
- While the consumption of recycled water of each technology is not taken into account, the total amount of makeup water is added to the operating cost of the wastewater treatment.
- Fixed operating cost: 5.1% of total capital cost.
- Using material and energy consumption data and the unit price, the annual cost (= the annualized capital cost + the operating cost) is calculated as shown in Figures S3-S6.



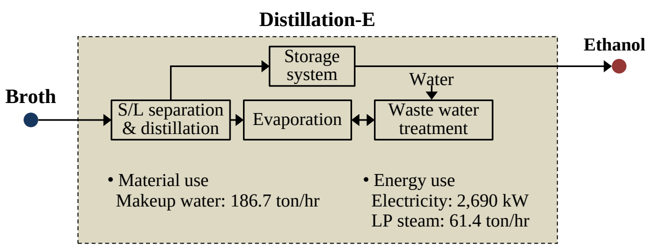

- Annualized capital cost: 112.2 M$ × 0.1175 = **13.2 M$/year**
- Variable operating cost: **17.3 M$/year**
  - Sulfuric acid : 32,352 ton/year × 33.2$/ton = 1.1 M$/year
  - Lime: 53,655 ton/year × 93.1$/ton = 5.0 M$/year
  - LP steam: 31,755 ton/year × 10.5$/ton = 0.3 M$/year
  - HP steam: 330,690 ton/year × 14.5$/ton = 4.8 M$/year
  - Electricity: 42.2 GWh/year × 0.06$/kWh = 2.5 M$/year
  - Gypsum disposal: 121,180 ton/year × 29.6$/ton = 3.6 M$/year
- Fixed operating cost: 112.2 M$ × 0.0512 = **5.7 M$/year**
- **Total annual cost**: **36.2 M$/year**

**Fig. S3.** Annual cost calculation of technology DA pretreatment.



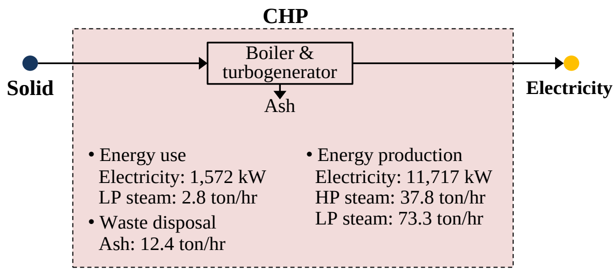

- Annualized capital cost: 51.9 M$ × 0.1175 = **6.1 M$/year**
- Variable operating cost: **49.0 M$/year**
  - CSL: 39,420 ton/year × 215$/ton = 8.5 M$/year
  - Enzyme: 76,282 ton/year × 507$/ton = 38.7 M$/year
  - LP steam: 48,180 ton/year × 10.5$/ton = 0.5 M$/year
  - Electricity: 23.3 GWh/year × 0.06$/kWh = 1.4 M$/year
- Fixed operating cost: 51.9 M$ × 0.0512 = **2.7 M$/year**
- **Total annual cost**: **57.8 M$/year**

**Fig. S4.** Annual cost calculation of technology SSF.




- Annualized capital cost: 78.1 M$ × 0.1175 = **9.2 M$/year**
- Variable operating cost: **8.7 M$/year**
  - Water: 1.6 Mton/year × 1$/ton = 1.6 M$/year
  - LP steam: 538,013 ton/year × 10.5$/ton = 5.6 M$/year
  - Electricity: 23.5 GWh/year × 0.06$/kWh = 1.4 M$/year
- Fixed operating cost: 78.1 M$ × 0.0512 = **4.0 M$/year**
- **Total annual cost**: **21.9 M$/year**

**Fig. S5.** Annual cost calculation of technology Distillation-E.




- Annualized capital cost: 133.6 M$ × 0.1175 = **15.7 M$/year**
- Variable operating cost: **4.3 M$/year**
  - LP steam: 24,528 ton/year × 10.5$/ton = 0.3 M$/year
  - Electricity: 13.8 GWh/year × 0.06$/kWh = 0.8 M$/year
  - Ash disposal: 108,405 ton/year × 29.6$/ton = 3.2 M$/year
- Fixed operating cost: 133.6 M$ × 0.0512 = **6.8 M$/year**
- Energy production credit: **-17.7 M$/year**
  - HP steam: -330.690 ton/year × 14.5$/ton = -4.8 M$/year
  - LP steam: -638,095 ton/year × 10.5$/ton = -6.7 M$/year
  - Electricity: -103.3 GWh/year × 0.06$/kWh = -6.2 M$/year
- **Total annual cost**: **9.1 M$/year**

**Fig. S6.** Annual cost calculation of technology CHP.

Finally, the technical and economical parameters (i.e., yield, unit production cost and energy requirement) are calculated as shown in Table S6.

**Table S6.** Technical and economical parameters of technologies.

| | DA pretreatment | SSF | Distillation-E | CHP |
|---|---|---|---|---|
| A. Amount of reactant (kg/hr) | 111,125 | 416,125 | 429,208 | 46,355 |
| B. Amount of product (kg/hr) | 416,125 | 429,208 | 19,042/46,355 | 24,756 |
| C. Total annual cost (M$/y) | 36.2 | 57.8 | 21.9 | 9.1 |
| D. Total energy use (MW) | 36.8 | 6.8 | 48.7 | 3.6 |
| **Yield [=B/A]** | **3.745** | **1.031** | **0.044/0.108** | **0.534** |
| **Unit production cost [=C/B/8600]($/kg)** | **0.010** | **0.015** | **0.131** | **0.042** |
| **Energy requirement [=1000D/B](kWh/kg)** | **0.089** | **0.016** | **2.556** | **0.147** |

# B. Assumptions for parameter evaluation

## B1. Direct cost and investment cost estimations

If only equipment purchased costs are available from literature, the direct installed costs are estimated using the installation factors listed in Table S7.

**Table S7.** Installation factors.

| Equipment | Installation factor[1] |
|---|---|
| Agitators – carbon steel (CS) | 1.3-1.4 |
| Agitators – stainless steel (SS) | 1.2-1.3 |
| Boilers | 1.3 |
| Compressors (motor driven) | 1.3 |
| Cooling towers | 1.2 |
| Distillation columns – carbon steel | 3.0 |
| Distillation columns – stainless steel | 2.1 |
| Filters | 1.4 |
| Heat exchangers (S&T) | 2.1 |
| Pumps – lobe | 1.2-1.4 |
| Pumps – centrifugal, carbon steel | 2.8 |
| Pumps – centrifugal, stainless steel | 2.0 |
| Pressure vessels – carbon steel | 2.8 |
| Pressure vessels – stainless steel | 1.7 |
| Tanks – field erected, carbon steel | 1.4 |
| Tanks – field erected, carbon steel with lining | 1.6 |
| Tanks – field erected, stainless steel | 1.2 |
| Solids handling equipment | 1.2-1.4 |
| Turbogenerator | 1.5 |

[1] Installed cost = (Purchased equipment cost) × (Installation factor)

If there is no sufficient information for costs, the total capital cost can be estimated from the total purchased equipment cost using the capital investment factors in Table S8.

**Table S8.** Capital investment factors.

| | |
|---|---|
| Total purchased equipment cost | 100% |
| Purchased equipment installation | 39% |
| Instrumentation and controls | 26% |
| Piping | 31% |
| Electrical systems | 10% |
| Buildings (including services) | 29% |
| Yard improvements | 12% |
| Total direct cost | 247% |
| Indirect cost | |
| Engineering | 32% |
| Construction | 34% |
| Legal and contractors fees | 23% |
| Project contingency | 37% |
| Total indirect cost | 126% |
| Total capital cost | 373% |

## B.2. Fixed operating cost estimation

**Table S9.** Fixed operating cost factors.

| | |
|---|---|
| Labor charge | 2% of direct cost |
| Overhead | 60% of labor charge |
| Maintenance | 7% of total equipment cost |
| General & administrative | 5% of direct cost |
| Tax & insurance | 2% of capital cost |

## B.3. Time-value adjustment

**Table S10.** Time-value index factor for capital, chemical and labor costs.

| | Capital index | Chemical index | Labor index |
|---|---|---|---|
| 1996 | 381.7 | 142.1 | 15.37 |
| 1997 | 386.5 | 147.1 | 15.78 |
| 1998 | 389.5 | 148.7 | 16.23 |
| 1999 | 390.6 | 149.7 | 16.40 |
| 2000 | 394.1 | 156.7 | 17.09 |
| 2001 | 394.3 | 158.4 | 17.57 |
| 2002 | 395.6 | 157.3 | 17.97 |
| 2003 | 402.0 | 164.6 | 18.50 |
| 2004 | 444.0 | 172.8 | 19.16 |
| 2005 | 468.2 | 187.3 | 19.67 |
| 2006 | 499.6 | 196.8 | 19.60 |
| 2007 | 525.4 | 203.3 | 19.56 |

## B.4. Composition of biomass feedstock

**Table S11.** Compositions of crop biomass feedstocks.

| Composition % (dry weight fraction) | Soybean | Corn[1] | Sugarcane[2] |
|---|---|---|---|
| Protein (%) | 40.63 | 13.33 | 6.19 |
| Fat (oil) (%) | 21.25 | 4.92 | 2.61 |
| Starch (%) | 21.25 | 54.50 | 59.71 |
| Fiber (%) | 13.13 | 11.25 | 12.56 |
| Sugar (%) | 0.00 | 13.42 | 14.72 |
| Ash (%) | 3.75 | 2.58 | 4.21 |
| Moisture fraction | 68.00 | 76.00 | 70.00 |

[1] The whole kernel includes endosperm, germ, bran coat and tip cap.
[2] The sugarcane includes leaf and stalk.

**Table S12.** Compositions of lignocellulosic biomass feedstocks.

| Composition % (dry weight fraction) | Sugarcane bagasse | Corn stover | Hard wood | Soft wood | Switchgrass |
|---|---|---|---|---|---|
| Total cellulose (%) | 38.10 | 37.70 | 42.90 | 44.50 | 32.90 |
| Glucan (C6) (%) | 38.10 | 37.70 | 42.90 | 44.50 | 32.90 |
| Total hemicellulose (%) | 25.08 | 25.30 | 20.30 | 21.90 | 25.20 |
| Xylan (C5) (%) | 21.80 | 21.30 | 16.90 | 6.30 | 21.10 |
| Arabinan (C5) (%) | 2.21 | 2.42 | 1.19 | 1.60 | 2.84 |
| Galactan (C6) (%) | 0.77 | 0.87 | 0.70 | 2.56 | 0.95 |
| Mannan (C6) (%) | 0.30 | 0.38 | 1.42 | 11.40 | 0.30 |
| Lignin (%) | 18.40 | 18.60 | 26.60 | 27.70 | 18.10 |
| Acids (%) | 2.80 | 2.90 | 3.11 | 2.67 | 1.21 |
| Extractives (%) | 5.84 | 5.61 | 4.70 | 2.88 | 13.62 |
| Ash (%) | 9.78 | 10.17 | 2.43 | 0.32 | 8.95 |
| Moisture fraction | 20.00 | 20.00 | 25.00 | 25.00 | 20.00 |

# C. Economical and technical parameters of technologies

**Assumptions**

- Capacity of individual technology: to handle 2,000 dry ton /day of feedstock
- Reference year: 2007

**Abbreviations**

- CAP: Capacity, CC: Capital cost, OC: Operating cost, UPC: Unit production cost, ER: Energy requirement
- Technology names are expressed as *Group name_Processing compound_Number*.
  - ***Group name***
    AC: Acidic, AFEX: Ammonia fiber expansion based pretreatment, APR: Aqueous phase reforming, CAT: Catalytic conversion technology, CHP: Combined heat and power generation, CON: Conditioning, D: Direct, DA: Dilute acid, D & F: Drying & filtering, FT: Fischer-Tropsch, HW: Hot water, HYDRO: Hydrogenation, H & C: Handling & chopping, H & E: Handling & extraction, H & M: Handling & milling, H & S: Handling & steeping, ID Indirect, LIQ & SACC: Liquefaction & saccharification, MTG: Methanol to gasoline technology, OLIGO: Oligomerization, SEP: Separation, SR: Steam reforming, SSF: Simultaneous saccharification and fermentation, SYN: Chemical synthesis technology.
  - ***Processing compound***
    AA: Acetic acid, AL: Alkanes, B: Butanol, BA: Bagasse, BM: Biomass, BN: Butene, BO: Bio-oil, C: Corn, CB: Crude bio-oil, DBK: Dibutyl ketone, DC: Dry corn, DDGS: Dried grains with soluble, E: Ethanol, EL: Ethyl levulinate, FA: Fuel additives, GVL: γ-valerolactone, LA: Levulinic acid, LH: Lignin and humans, M: Methanol, MA: Mixed alcohol (Ethanol, propanol, butanol and pentanol), RS: Raw syngas, SB: Soybean, SC: Sugarcane, SNG: Synthesized natural gas, TAR: Tar residue, WC: Wet corn.

**Table S13.** Technical and economic parameters of technologies.

| Group | Technology | Input | Output | Yield[1] | CAP (kg/hr) | CC (M$) | OC (M$/y) | UPC ($/kg) | ER (Wh/kg) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| H & E | H&E_1 | Soybean | Triglyceride_1 | 1.508 | 26,375 | 2.84 | 1.25 | 0.007 | 0.003 | 1-3 |
| Transesterification | Transester_1 | Triglyceride_1 | Crude biodiesel_1 | 1.102 | 29,055 | 7.27 | 2.87 | 0.015 | 0.004 | 1-3 |
| Distil-SB | Distil-SB_1 | Crude biodiesel_1 | Biodiesel | 0.600 | 17,431 | 7.76 | 4.92 | 0.039 | 0.017 | 1-3 |
| | | | Raw glycerol_1 | 1.826 | | | | | | |
| PURI-G | Puri-Gl_1 | Raw glycerol_1 | Glycerol | 0.599 | 31,777 | 5.46 | 3.46 | 0.015 | 0.009 | 1-3 |
| APR & FT | APR & FT_1 | Glycerol | Gasoline | 0.203 | 6,442 | 3.90 | 1.44 | 0.009 | 0.272 | 1-3 |
| | | | SNG | 0.070 | | | | | | |
| H&M | H&M-corn_1 | Corn | Dry corn_1 | 1.000 | 43,117 | 7.82 | 0.75 | 0.005 | 0.040 | 4-6 |
| LIQ&SACC-DC | Liq&sacch-DC_1 | Dry corn_1 | DC slurry_1 | 2.670 | 115,123 | 9.75 | 3.71 | 0.005 | 0.137 | 4-6 |
| Fer-DC | Fer-DC _1 | DC slurry_1 | DC broth-E_1 | 1.112 | 128,057 | 23.11 | 1.26 | 0.004 | 0.003 | 4-6 |
| | Fer-DC _2 | DC slurry _1 | DC broth-B_1 | 0.557 | 64,146 | 25.78 | 5.92 | 0.016 | 0.019 | 4-8 |
| Distil-DC | Distil-DC _1 | DC broth-E _1 | Ethanol | 0.108 | 13,799 | 28.11 | 7.19 | 0.088 | 2.045 | 4-6 |
| | | | Solid-C_1 | 0.822 | | | | | | |
| | Distil-DC _2 | DC broth-B _1 | Ethanol | 0.001 | 63 | 76.07 | 25.00 | 62.642 | 1433.333 | 4-8 |
| | | | Solid-C_2 | 0.659 | | | | | | |
| | | | Butanol | 0.159 | | | | | | |
| | | | Acetone | 0.036 | | | | | | |
| | | | Fiber | 0.141 | | | | | | |
| H & S | H&S_1 | Corn | Wet corn_1 | 1.379 | 59,467 | 7.94 | 1.61 | 0.005 | 0.062 | 4,5,9 |
| | | | Gluten | 0.303 | | | | | | |
| LIQ&SACC-WC | Liq&sacch_WC_1 | Wet corn_1 | WC slurry _1 | 1.587 | 94,401 | 8.29 | 3.06 | 0.005 | 0.149 | 4,5,9 |
| Fer-WC | Fer-WC_1 | WC slurry _1 | WC broth _1 | 1.112 | 105,008 | 19.64 | 1.07 | 0.004 | 0.003 | 4,5,9 |
| Distil-WC | Distil-WC _1 | WC broth _1 | Ethanol | 0.108 | 11,314 | 23.89 | 6.48 | 0.095 | 2.220 | 4,5,9 |
| | | | Solid-C_3 | 0.892 | | | | | | |
| Extraction | Extraction_1 | Sugarcane | SC juice_1 | 0.670 | 115,221 | 9.42 | 0.25 | 0.001 | 0.018 | 10-12 |
| | | | Solid-SC_1 | 0.260 | | | | | | |
| H & D | H&D_1 | Solid-SC_1 | Raw bagasse | 0.667 | 29,809 | 40.51 | 1.28 | 0.009 | 0.004 | 10-12 |
| Filtration | Filtration_1 | SC juice_1 | Slurry-SC_1 | 0.999 | 115,123 | 11.60 | 4.51 | 0.006 | 0.137 | 10-12 |
| Fer-SC | Fer-SC_1 | Slurry-SC_1 | Fermented-SC_1 | 1.112 | 128,057 | 24.20 | 1.36 | 0.004 | 0.003 | 10-12 |
| Distil-SC | Distil-SC _1 | Broth-SC _1 | Ethanol | 0.108 | 13,799 | 37.40 | 7.42 | 0.100 | 2.045 | 10-12 |
| Treating-BA | Treating-BA_1 | Raw bagasse | Bagasse | 1.157 | 128,542 | 22.10 | 1.33 | 0.004 | 0.001 | 10-12 |
| Esterification | Ester_1 | LA | EL | 0.791 | 15,833 | 0.00 | 0.00 | 0.071 | 0.606 | 13-17 |
| BioFine | Biofine_1 | Corn stover | LA | 0.133 | 17,142 | 0.00 | 0.00 | 0.090 | 0.758 | 13-17 |
| | | | Formic acid | 0.053 | | | | | | |
| | | | Biofine tar_1 | 0.309 | | | | | | |
| | Biofine_2 | Sugarcane | LA | 0.120 | 15,469 | 0.00 | 0.00 | 0.090 | 0.840 | 13-17 |
| | | | Formic acid | 0.048 | | | | | | |
| | | | Biofine tar_1 | 0.333 | | | | | | |

**Table S13.** (Continued)

| Group | Technology | Input | Output | Yield | CAP (kg/hr) | CC (M$) | OC (M$/y) | UPC ($/kg) | ER (Wh/kg) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| BioFine | Biofine_3 | Hard wood | LA | 0.146 | 24,383 | 0.00 | 0.00 | 0.090 | 0.533 | 13-17 |
| | | | Formic Acid | 0.059 | | | | | | |
| | | | Biofine tar_1 | 0.252 | | | | | | |
| | Biofine_4 | Soft wood | LA | 0.120 | 20,015 | 0.00 | 0.00 | 0.090 | 0.649 | 13-17 |
| | | | Formic Acid | 0.048 | | | | | | |
| | | | Biofine tar_1 | 0.265 | | | | | | |
| CHP-TAR | CHP-TAR_1 | Tar_biofine_1 | Electricity | 1.926 | 84,894 | 195.00 | 9.80 | 0.045 | 0.001 | 13-17 |
| DA Pretreatment | DA Pret_1 | Corn stover | Hydrolyzate_1 | 3.745 | 416,125 | 112.20 | 23.00 | 0.010 | 89.214 | 18-20 |
| | DA Pret_2 | Hard wood | Hydrolyzate_4 | 3.610 | 520,001 | 121.63 | 20.11 | 0.008 | 71.424 | 18-20 |
| | DA Pret_3 | Soft wood | Hydrolyzate_7 | 3.598 | 520,001 | 121.63 | 20.11 | 0.008 | 71.424 | 18-20 |
| | DA Pret_4 | Sugarcane | Hydrolyzate_10 | 3.743 | 416,125 | 112.20 | 23.20 | 0.010 | 89.214 | 18-20 |
| AFEX Pretreatment | AFEX Pret_1 | Corn stover | Hydrolyzate_3 | 3.923 | 435,875 | 20.72 | 4.72 | 0.002 | 78.968 | 18-20 |
| | AFEX Pret_2 | Soft wood | Hydrolyzate_6 | 3.928 | 565,835 | 19.17 | 8.94 | 0.002 | 60.831 | 18-20 |
| | AFEX Pret_3 | Hard wood | Hydrolyzate_9 | 3.923 | 565,168 | 19.69 | 8.94 | 0.002 | 60.902 | 18-20 |
| | AFEX Pret_4 | Sugarcane | Hydrolyzate_12 | 3.923 | 435,875 | 20.01 | 5.43 | 0.002 | 78.968 | 18-20 |
| HW Pretreatment | HW Pret_1 | Corn stover | Hydrolyzate_2 | 4.907 | 545,125 | 20.72 | 4.72 | 0.001 | 126.936 | 18-20 |
| | HW Pret_2 | Soft wood | Hydrolyzate_5 | 4.767 | 686,668 | 18.17 | 8.30 | 0.002 | 102.462 | 18-20 |
| | HW Pret_3 | Hard wood | Hydrolyzate_8 | 4.720 | 680,001 | 17.69 | 6.57 | 0.001 | 103.467 | 18-20 |
| | HW Pret_4 | Sugarcane | Hydrolyzate_11 | 4.907 | 545,125 | 20.19 | 5.15 | 0.002 | 126.936 | 18-20 |
| SSF | SSF_1 | Hydrolyzate_1 | Broth_1 | 1.031 | 429,208 | 51.9 | 51.7 | 0.015 | 16.483 | 18-29 |
| | SSF_2 | Hydrolyzate_2 | Broth_2 | 1.028 | 560,500 | 71.9 | 55.2 | 0.013 | 13.837 | 18-29 |
| | SSF_3 | Hydrolyzate_3 | Broth_3 | 1.031 | 449,417 | 56.0 | 52.3 | 0.014 | 14.595 | 18-29 |
| | SSF_4 | Hydrolyzate_4 | Broth_7 | 0.945 | 491,401 | 48.0 | 68.1 | 0.013 | 14.755 | 18-29 |
| | SSF_5 | Hydrolyzate_5 | Broth_8 | 1.068 | 733,362 | 66.5 | 68.4 | 0.012 | 10.576 | 18-29 |
| | SSF_6 | Hydrolyzate_6 | Broth_9 | 1.036 | 586,205 | 51.8 | 59.4 | 0.013 | 11.189 | 18-29 |
| | SSF_7 | Hydrolyzate_7 | Broth_10 | 0.945 | 491,401 | 84.9 | 73.1 | 0.016 | 14.755 | 18-29 |
| | SSF_8 | Hydrolyzate_8 | Broth_11 | 1.110 | 754,802 | 94.1 | 58.8 | 0.011 | 10.276 | 18-29 |
| | SSF_9 | Hydrolyzate_9 | Broth_12 | 1.042 | 588,905 | 78.4 | 56.2 | 0.011 | 11.138 | 18-29 |
| | SSF_10 | Hydrolyzate_10 | Broth_13 | 1.031 | 429,208 | 64.4 | 56.6 | 0.012 | 16.483 | 18-29 |
| | SSF_11 | Hydrolyzate_11 | Broth_14 | 1.028 | 560,500 | 68.8 | 62.0 | 0.013 | 13.837 | 18-29 |
| | SSF_12 | Hydrolyzate_12 | Broth_15 | 1.031 | 449,417 | 65.1 | 57.5 | 0.013 | 14.595 | 18-29 |
| Fermentation | Fer_1 | Slurry_1 | Broth_4 | 0.991 | 420,000 | 2.10 | 4.16 | 0.001 | 25.175 | 18-29 |
| | Fer_2 | Slurry_2 | Broth_5 | 0.981 | 525,150 | 17.53 | 2.30 | 0.001 | 20.738 | 18-29 |
| | Fer_3 | Slurry_3 | Broth_6 | 0.981 | 419,898 | 17.53 | 2.30 | 0.001 | 24.425 | 18-29 |
| | Fer_4 | Slurry_4 | Broth_16 | 0.991 | 420,000 | 2.10 | 4.16 | 0.001 | 25.175 | 18-29 |
| | Fer_5 | Slurry_5 | Broth_17 | 0.981 | 525,150 | 2.30 | 4.36 | 0.001 | 20.738 | 18-29 |
| | Fer_6 | Slurry_6 | Broth_18 | 0.981 | 419,898 | 2.30 | 4.36 | 0.001 | 24.425 | 18-29 |

**Table S13.** (Continued)

| Group | Technology | Input | Output | Yield | CAP (kg/hr) | CC (M$) | OC (M$/y) | UPC ($/kg) | ER (Wh/kg) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| AC Hydrolysis | AC Hyd_1 | Hydrolyzate_1 | Slurry_1 | 1.019 | 423,875 | 18.36 | 1.24 | 0.001 | 1.246 | 18-29 |
| | AC Hyd_2 | Hydrolyzate_2 | Slurry_2 | 0.982 | 535,260 | 18.36 | 1.30 | 0.001 | 1.016 | 18-29 |
| | AC Hyd_3 | Hydrolyzate_3 | Slurry_3 | 0.982 | 427,987 | 18.36 | 1.30 | 0.001 | 1.197 | 18-29 |
| | AC Hyd_4 | Hydrolyzate_10 | Slurry_4 | 1.019 | 423,875 | 1.24 | 3.40 | 0.001 | 1.246 | 18-29 |
| | AC Hyd_5 | Hydrolyzate_11 | Slurry_5 | 0.982 | 535,260 | 1.30 | 3.46 | 0.001 | 1.016 | 18-29 |
| | AC Hyd_6 | Hydrolyzate_12 | Slurry_6 | 0.982 | 427,987 | 1.30 | 3.46 | 0.001 | 1.197 | 18-29 |
| Distillation-E | Distil-E_1 | Broth_1 | Ethanol | 0.044 | 19,042 | 78.10 | 12.70 | 0.131 | 2556.142 | 18-29 |
| | | | Residue_1 | 0.108 | | | | | | |
| | Distil-E_2 | Broth_2 | Ethanol | 0.025 | 13,917 | 87.84 | 7.88 | 0.149 | 3834.213 | 18-29 |
| | | | Residue_2 | 0.109 | | | | | | |
| | Distil-E_3 | Broth_3 | Ethanol | 0.037 | 16,500 | 82.76 | 7.91 | 0.122 | 2735.070 | 18-29 |
| | | | Residue_3 | 0.133 | | | | | | |
| | Distil-E_4 | Broth_4 | Ethanol | 0.028 | 11,696 | 96.31 | 14.44 | 0.251 | 2735.070 | 18-29 |
| | | | Residue_4 | 0.258 | | | | | | |
| | Distil-E_5 | Broth_5 | Ethanol | 0.017 | 8,748 | 96.08 | 9.20 | 0.267 | 3766.470 | 18-29 |
| | | | Residue_5 | 0.215 | | | | | | |
| | Distil-E_6 | Broth_6 | Ethanol | 0.024 | 10,134 | 96.31 | 9.73 | 0.237 | 3061.940 | 18-29 |
| | | | Residue_6 | 0.261 | | | | | | |
| | Distil-E_7 | Broth_7 | Ethanol | 0.043 | 21,328 | 69.21 | 12.88 | 0.112 | 2556.089 | 18-29 |
| | | | Residue_1 | 0.090 | | | | | | |
| | Distil-E_8 | Broth_8 | Ethanol | 0.021 | 15,588 | 77.70 | 7.31 | 0.120 | 3834.308 | 18-29 |
| | | | Residue_2 | 0.081 | | | | | | |
| | Distil-E_9 | Broth_9 | Ethanol | 0.032 | 18,481 | 73.20 | 7.44 | 0.099 | 2735.162 | 18-29 |
| | | | Residue_3 | 0.099 | | | | | | |
| | Distil-E_10 | Broth_10 | Ethanol | 0.038 | 18,687 | 67.78 | 25.85 | 0.207 | 2556.195 | 18-29 |
| | | | Residue_1 | 0.095 | | | | | | |
| | Distil-E_11 | Broth_11 | Ethanol | 0.018 | 13,657 | 59.30 | 24.74 | 0.265 | 3834.213 | 18-29 |
| | | | Residue_2 | 0.082 | | | | | | |
| | Distil-E_12 | Broth_12 | Ethanol | 0.028 | 16,192 | 59.30 | 23.80 | 0.217 | 2735.172 | 18-29 |
| | | | Residue_3 | 0.102 | | | | | | |
| | Distil-E_13 | Broth_13 | Ethanol | 0.041 | 17,519 | 70.79 | 25.28 | 0.219 | 2556.103 | 18-29 |
| | | | Residue_1 | 0.112 | | | | | | |
| | Distil-E_14 | Broth_14 | Ethanol | 0.023 | 12,804 | 57.79 | 22.53 | 0.261 | 3834.171 | 18-29 |
| | | | Residue_2 | 0.111 | | | | | | |
| | Distil-E_15 | Broth_15 | Ethanol | 0.034 | 15,180 | 57.79 | 21.68 | 0.214 | 2735.014 | 18-29 |
| | | | Residue_3 | 0.136 | | | | | | |

**Table S13.** (Continued)

| Group | Technology | Input | Output | Yield | CAP (kg/hr) | CC (M$) | OC (M$/y) | UPC ($/kg) | ER (Wh/kg) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| Distillation-E | Distil-E_16 | Broth_16 | Ethanol | 0.026 | 10,760 | 78.39 | 30.04 | 0.416 | 2735.200 | 18-29 |
| | | | Residue_4 | 0.261 | | | | | | |
| | Distil-E_17 | Broth_17 | Ethanol | 0.015 | 8,048 | 63.20 | 25.24 | 0.463 | 3766.449 | 18-29 |
| | | | Residue_5 | 0.217 | | | | | | |
| | Distil-E_18 | Broth_18 | Ethanol | 0.022 | 9,323 | 62.77 | 25.71 | 0.405 | 3061.884 | 18-29 |
| | | | Residue_6 | 0.263 | | | | | | |
| Pervaporation | Perv_1 | Broth_1 | Ethanol | 0.045 | 19,220 | 178.99 | 15.98 | 0.224 | 656.712 | 21 |
| | | | Residue_7 | 0.106 | | | | | | |
| | Perv_2 | Broth_2 | Ethanol | 0.025 | 14,072 | 178.99 | 10.78 | 0.263 | 983.300 | 21 |
| | | | Residue_8 | 0.108 | | | | | | |
| | Perv_3 | Broth_3 | Ethanol | 0.037 | 16,755 | 178.99 | 11.18 | 0.224 | 698.499 | 21 |
| | | | Residue_9 | 0.131 | | | | | | |
| | Perv_4 | Broth_4 | Ethanol | 0.028 | 11,576 | 178.99 | 16.58 | 0.378 | 716.600 | 21 |
| | | | Residue_10 | 0.254 | | | | | | |
| | Perv_5 | Broth_5 | Ethanol | 0.017 | 8,829 | 178.99 | 11.48 | 0.428 | 967.720 | 21 |
| | | | Residue_11 | 0.212 | | | | | | |
| | Perv_6 | Broth_6 | Ethanol | 0.024 | 10,229 | 178.99 | 11.98 | 0.375 | 786.685 | 21 |
| | | | Residue_12 | 0.257 | | | | | | |
| | Perv_7 | Broth_7 | Ethanol | 0.050 | 21,527 | 178.99 | 16.80 | 0.204 | 656.710 | 21 |
| | | | Residue_7 | 0.101 | | | | | | |
| | Perv_8 | Broth_8 | Ethanol | 0.028 | 15,734 | 178.99 | 10.97 | 0.236 | 983.348 | 21 |
| | | | Residue_8 | 0.105 | | | | | | |
| | Perv_9 | Broth_9 | Ethanol | 0.042 | 18,656 | 178.99 | 11.41 | 0.202 | 698.488 | 21 |
| | | | Residue_9 | 0.126 | | | | | | |
| | Perv_10 | Broth_10 | Ethanol | 0.044 | 18,861 | 15.85 | 36.88 | 0.227 | 656.699 | 21 |
| | | | Residue_7 | 0.107 | | | | | | |
| | Perv_11 | Broth_11 | Ethanol | 0.025 | 13,785 | 13.75 | 34.78 | 0.293 | 983.315 | 21 |
| | | | Residue_8 | 0.108 | | | | | | |
| | Perv_12 | Broth_12 | Ethanol | 0.036 | 16,343 | 11.13 | 32.16 | 0.229 | 698.464 | 21 |
| | | | Residue_9 | 0.132 | | | | | | |
| | Perv_13 | Broth_13 | Ethanol | 0.041 | 17,682 | 15.44 | 36.47 | 0.240 | 656.698 | 21 |
| | | | Residue_7 | 0.110 | | | | | | |
| | Perv_14 | Broth_14 | Ethanol | 0.023 | 12,946 | 10.65 | 31.68 | 0.285 | 983.297 | 21 |
| | | | Residue_8 | 0.110 | | | | | | |
| | Perv_15 | Broth_15 | Ethanol | 0.034 | 15,414 | 11.02 | 32.05 | 0.242 | 698.450 | 21 |
| | | | Residue_9 | 0.134 | | | | | | |
| | Perv_16 | Broth_16 | Ethanol | 0.025 | 10,649 | 15.99 | 37.02 | 0.404 | 716.656 | 21 |

**Table S13.** (Continued)

| Group | Technology | Input | Output | Yield | CAP (kg/hr) | CC (M$) | OC (M$/y) | UPC ($/kg) | ER (Wh/kg) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| Pervaporation | Perv_17 | Broth_17 | Ethanol | 0.015 | 8,123 | 11.30 | 32.33 | 0.463 | 967.784 | 21 |
| | | | Residue_11 | 0.213 | | | | | | |
| | Perv_18 | Broth_18 | Ethanol | 0.022 | 9,411 | 11.76 | 32.79 | 0.405 | 786.659 | 21 |
| | | | Residue_12 | 0.259 | | | | | | |
| CON-LA | CON-LA_1 | Hydrolyzate_1 | Solid LA_1 | 0.132 | 54,881 | 0.00 | 0.00 | 0.000 | 0.000 | 17,30,31 |
| | | | Xylose | 0.041 | | | | | | |
| | CON-LA_2 | Hydrolyzate_10 | Solid LA_2 | 0.132 | 54,732 | 0.00 | 0.00 | 0.000 | 0.000 | 17,30,31 |
| | | | Xylose | 0.043 | | | | | | |
| | CON-LA_3 | Hydrolyzate_4 | Solid LA_3 | 0.138 | 71,612 | 0.00 | 0.00 | 0.000 | 0.000 | 17,30,31 |
| | | | Xylose | 0.030 | | | | | | |
| | CON-LA_4 | Hydrolyzate_7 | Solid LA_4 | 0.135 | 70,235 | 0.00 | 0.00 | 0.000 | 0.000 | 17,30,31 |
| | | | Xylose | 0.024 | | | | | | |
| SEP-LA | SEP-LA_1 | Solid LA_1 | Raw LA_1 | 0.523 | 28,683 | 32.42 | 1.75 | 0.023 | 0.026 | 17,30,31 |
| | | | Residue LA_1 | 0.529 | | | | | | |
| | SEP-LA_2 | Solid LA_2 | Raw LA_1 | 0.473 | 25,884 | 32.42 | 1.71 | 0.025 | 0.029 | 17,30,31 |
| | | | Residue LA_1 | 0.559 | | | | | | |
| SEP-LA | SEP-LA_3 | Solid LA_3 | Raw LA_1 | 0.570 | 40,801 | 32.42 | 1.91 | 0.016 | 0.019 | 17,30,31 |
| | | | Residue LA_1 | 0.501 | | | | | | |
| | SEP-LA_4 | Solid LA_4 | Raw LA_1 | 0.477 | 33,492 | 32.42 | 1.81 | 0.020 | 0.023 | 17,30,31 |
| | | | Residue LA_1 | 0.556 | | | | | | |
| HYDRO-GVL | HYDRO-GVL_1 | Raw LA_1 | GVL_1 | 0.338 | 9,695 | 42.60 | 3.11 | 0.097 | 1.166 | 15,16,30 |
| CAT-BN | CAT-BN_1 | GVL_1 | Raw butene_1 | 0.962 | 9,323 | 27.07 | 2.48 | 0.071 | 1.491 | 15,16,30 |
| OLIGO | OLIGO_1 | Raw butene_1 | Alkenes_1 | 0.565 | 5,271 | 18.39 | 1.01 | 0.009 | 0.343 | 15,16,30 |
| CHP-LA | CHP-LA_1 | Residue LA_1 | Electricity | 1.926 | 55,891 | 154.00 | 6.70 | 0.052 | 0.000 | 15,16,21,30 |
| CAT-DBK | CAT-DBK_1 | LA | DBK | 0.415 | 8,298 | 31.70 | 3.60 | 0.103 | 0.868 | 15,17 |
| H & C | H&C_1 | Hard wood | Parti_1 | 0.535 | 94,696 | 40.51 | 2.61 | 0.009 | 0.002 | 32-44 |
| | H&C_2 | Soft wood | Parti_2 | 0.535 | 94,696 | 40.51 | 2.61 | 0.009 | 0.002 | 32-44 |
| | H&C_3 | Corn stover | Parti_3 | 0.802 | 94,696 | 40.51 | 1.81 | 0.008 | 0.002 | 32-44 |
| | H&C_4 | Switchgrass | Parti_4 | 0.802 | 94,696 | 40.51 | 1.81 | 0.008 | 0.002 | 32-44 |
| | H&C_5 | Hard wood | Parti_5 | 0.568 | 94,696 | 40.51 | 2.32 | 0.009 | 0.002 | 32-44 |
| | H&C_6 | Hard wood | Parti_6 | 0.585 | 97,429 | 81.02 | 13.39 | 0.027 | 0.006 | 32-44 |
| | H&C_7 | Soft wood | Parti_7 | 0.568 | 94,696 | 40.51 | 2.32 | 0.009 | 0.002 | 32-44 |
| | H&C_8 | Soft wood | Parti_8 | 0.585 | 97,429 | 81.02 | 13.39 | 0.027 | 0.006 | 32-44 |
| Direct gasification | D Gasi_1 | Parti_6 | Rawsyngas_2 | 1.159 | 112,934 | 150.99 | 10.79 | 0.029 | 0.081 | 32-44 |
| | D Gasi_2 | Parti_8 | Rawsyngas_4 | 1.188 | 115,711 | 10.79 | 28.53 | 0.029 | 0.079 | 32-44 |
| Indirect gasification | ID Gasi_1 | Parti_5 | Rawsyngas_1 | 0.843 | 79,819 | 62.61 | 6.26 | 0.020 | 0.060 | 32-44 |
| | ID Gasi_2 | Parti_7 | Rawsyngas_3 | 0.864 | 81,782 | 6.26 | 13.62 | 0.019 | 0.059 | 32-44 |

**Table S13.** (Continued)

| Group | Technology | Input | Output | Yield | CAP (kg/hr) | CC (M$) | OC (M$/y) | UPC ($/kg) | ER (Wh/kg) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| Pyrolysis | Pyrolysis_1 | Parti_1 | Raw biooil_1 | 0.771 | 68,768 | 51.49 | 7.79 | 0.023 | 1.832 | |
| | Pyrolysis_2 | Parti_2 | Raw biooil_1 | 0.755 | 67,317 | 51.49 | 7.12 | 0.023 | 1.738 | 40-54 |
| | Pyrolysis_3 | Parti_3 | Raw biooil_1 | 0.754 | 67,206 | 51.49 | 6.78 | 0.022 | 1.756 | 40-54 |
| | Pyrolysis_4 | Parti_4 | Raw biooil_1 | 0.753 | 67,148 | 51.49 | 6.60 | 0.022 | 1.742 | 40-54 |
| SEP-RE | SEP-RE_1 | Residue_1 | Residue lignin | 0.711 | 32,966 | 0.00 | 0.23 | 0.001 | 0.000 | 44 |
| | SEP-RE_1 | Residue_2 | Residue lignin | 0.640 | 39,243 | 0.00 | 0.31 | 0.001 | 0.000 | 44 |
| | SEP-RE_3 | Residue_3 | Residue lignin | 0.654 | 39,069 | 0.00 | 0.30 | 0.001 | 0.000 | 44 |
| | SEP-RE_4 | Residue_4 | Residue lignin | 0.633 | 68,652 | 0.00 | 0.54 | 0.001 | 0.000 | 44 |
| | SEP-RE_5 | Residue_5 | Residue lignin | 0.626 | 70,739 | 0.00 | 0.57 | 0.001 | 0.000 | 44 |
| | SEP-RE_6 | Residue_6 | Residue lignin | 0.633 | 69,375 | 0.00 | 0.55 | 0.001 | 0.000 | 44 |
| | SEP-RE_7 | Residue_7 | Residue lignin | 0.711 | 32,415 | 0.00 | 0.23 | 0.001 | 0.000 | 44 |
| | SEP-RE_8 | Residue_8 | Residue lignin | 0.640 | 38,587 | 0.00 | 0.30 | 0.001 | 0.000 | 44 |
| | SEP-RE_9 | Residue_9 | Residue lignin | 0.654 | 38,416 | 0.00 | 0.29 | 0.001 | 0.000 | 44 |
| | SEP-RE_10 | Residue_10 | Residue lignin | 0.633 | 67,505 | 0.00 | 0.53 | 0.001 | 0.000 | 44 |
| | SEP-RE_11 | Residue_11 | Residue lignin | 0.626 | 69,557 | 0.00 | 0.56 | 0.001 | 0.000 | 44 |
| | SEP-RE_12 | Residue_12 | Residue lignin | 0.633 | 68,215 | 0.00 | 0.54 | 0.001 | 0.000 | 44 |
| Pyrolysis-RE | Pyrolysis_RE_1 | Residue lignin | Raw biooil_1 | 0.257 | 8,466 | 33.94 | 7.21 | 0.154 | 944.240 | 44 |
| CHP | CHP_1 | Residue_1 | Electricity | 0.544 | 24,756 | 133.60 | (6.60) | 0.042 | 147.000 | 28,55,56 |
| | CHP_2 | Residue_2 | Electricity | 0.397 | 24,352 | 158.10 | (7.40) | 0.052 | 144.601 | 28,55,56 |
| | CHP_3 | Residue_3 | Electricity | 0.47 | 28,096 | 149.26 | (7.40) | 0.041 | 166.833 | 28,55,56 |
| | CHP_4 | Residue_4 | Electricity | 0.334 | 36,233 | 114.86 | (3.30) | 0.032 | 215.150 | 28,55,56 |
| | CHP_5 | Residue_5 | Electricity | 0.25 | 28,241 | 114.86 | (3.29) | 0.041 | 167.694 | 28,55,56 |
| | CHP_6 | Residue_6 | Electricity | 0.289 | 31,724 | 114.86 | (3.30) | 0.037 | 188.376 | 28,55,56 |
| | CHP_7 | Residue_7 | Electricity | 0.643 | 29,332 | 96.99 | (2.90) | 0.033 | 174.172 | 28,55,56 |
| | CHP_8 | Residue_8 | Electricity | 0.471 | 28,404 | 96.99 | (2.85) | 0.034 | 168.662 | 28,55,56 |
| | CHP_9 | Residue_9 | Electricity | 0.561 | 32,937 | 96.99 | (2.86) | 0.030 | 195.578 | 28,55,56 |
| | CHP_10 | Residue_10 | Electricity | 0.387 | 41,335 | 96.99 | (2.71) | 0.024 | 245.445 | 28,55,56 |
| | CHP_11 | Residue_11 | Electricity | 0.296 | 32,855 | 96.99 | (2.70) | 0.030 | 195.091 | 28,55,56 |
| | CHP_12 | Residue_12 | Electricity | 0.342 | 36,911 | 96.99 | (2.71) | 0.027 | 219.176 | 28,55,56 |
| SR-RS | SR-RS_1 | Rawsyngas_1 | Syngas | 0.631 | 50,341 | 157.25 | 11.22 | 0.069 | 0.040 | 33,37 |
| | SR-RS_2 | Rawsyngas_2 | Syngas | 0.543 | 61,328 | 143.63 | 8.57 | 0.048 | 0.067 | 33,37 |
| | SR-RS_3 | Rawsyngas_3 | Syngas | 0.631 | 51,579 | 29.70 | 0.07 | 0.067 | 0.016 | 33,37 |
| | SR-RS_4 | Rawsyngas_4 | Syngas | 0.543 | 62,836 | 25.44 | 0.05 | 0.047 | 0.009 | 33,37 |
| SYN-M | SYN-M_1 | Syngas | RawMeOH_1 | 0.862 | 43,417 | 37.49 | 9.12 | 0.036 | 0.062 | 35 |
| SYN-AA | SYN-AA_1 | RawMeOH_1 | AA | 1.809 | 73,203 | 75.13 | 109.85 | 0.189 | 0.015 | 35 |
| HYDRO | HYDRO_1 | AA | Ethanol | 0.764 | 55,898 | 127.42 | 107.53 | 0.255 | 0.005 | 35 |
| MTG | MTG_1 | RawMeOH_1 | Gasoline | 0.323 | 14,033 | 89.97 | 19.11 | 0.246 | 0.214 | 36,42 |

**Table S13.** (Continued)

| Group | Technology | Input | Output | Yield | CAP (kg/hr) | CC (M$) | OC (M$/y) | UPC ($/kg) | ER (Wh/kg) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| Hydrotreating | Hydrotreating_1 | rawbiooil_1 | Bio-oil | 0.458 | 31,522 | 44.00 | 12.69 | 0.107 | 376.309 | 34,36 |
| Hydrocracking | Hydrocracking_1 | Bio-oil | Gasoline | 0.411 | 12,952 | 44.00 | 12.69 | 0.160 | 132.798 | 46,50 |
| | | | Diesel | 0.552 | | | | | | |
| SYN-MA | SYN-MA_1 | Syngas | Ethanol | 0.377 | 19,000 | 0.00 | 0.00 | 0.812 | 0.742 | 57 |
| | | | Propanol | 0.100 | | | | | | |
| | | | Butanol | 0.053 | | | | | | |
| | | | Pentanol | 0.025 | | | | | | |
| Fischer-Tropsch | F-T_1 | Syngas | Gasoline | 0.133 | 3,174 | 12.48 | 0.46 | 0.457 | 0.693 | 33,37 |
| | | | Diesel | 0.110 | | | | | | |

[1] Note that the yield of a technology may be larger than 1 due to an auxiliary mass input (*e.g.*, water).

## References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