Design of Cellulosic Ethanol Supply Chains with Regional Depots

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SUPPORTING INFORMATION

Big-M reformulation in Section 4. Remarks.

We first calculate lower and upper bounds, $x^{\mathrm{L}}/y^{\mathrm{L}}$ and $x^{\mathrm{U}}/y^{\mathrm{U}}$, based on maximum and minimum values of the Cartesian coordinates of farms and biorefineries. The Cartesian coordinates of depots are then bounded as follows:

$$x^{\mathrm{L}} \leq x_k^* \leq x^{\mathrm{U}} \tag{S1}$$

$$y^{\mathrm{L}} \leq y_k^* \leq y^{\mathrm{U}} \tag{S2}$$

Equations (55) – (57) can be replaced by the following equations:

$$\Delta x_{j,k} \leq (\Delta x_{j,l} + \epsilon) Z_{j,k}\,, \quad j,k,l \tag{S3}$$

$$\Delta y_{j,k} \leq (\Delta y_{j,l} + \epsilon) Z_{j,k}\,, \quad j,k,l \tag{S4}$$

$$D_{j,k} \leq \tau_{j,l} Z_{j,k}\,, \quad j,k,l \tag{S5}$$

where ϵ = 5 km. Note that the minimum value of $\Delta x_{j,l}$ will be essentially used as a big-M value when more than one biorefineries are considered.

The distance between the depot and the biorefinery must be less than the distance between the farthest farm and the biorefinery, which are given:

$$\Delta x_{k,l} \leq \max\{|x^{\mathrm{U}} - x_l|, |x_l - x^{\mathrm{L}}|\} Z_{k,l}\,, \quad k,l \tag{S6}$$

$$\Delta y_{k,l} \leq \max\{|y^{\mathrm{U}} - y_l|, |y_l - y^{\mathrm{L}}|\} Z_{k,l}\,, \quad k,l \tag{S7}$$

$$D_{k,l} \leq \left(\max\{|x^{\mathrm{U}} - x_l|, |x_l - x^{\mathrm{L}}|\} + \max\{|y^{\mathrm{U}} - y_l|, |y_l - y^{\mathrm{L}}|\}\right) Z_{k,l}\,, \quad k,l \tag{S8}$$

Data for case study in Section 5. Application.

Table S1 gives the coordinates of farms and biorefineries, as extracted from Google Maps[1]. Biomass availability[2–4] for each time period is tabulated in **Table S2**. The biomass acquisition cost and CO_2 emissions during biomass collection are summarized in **Table S3**. Note that the biomass acquisition cost includes labor, fuel use, equipment, nutrient replacement and handling costs at farms[5,6]. CO_2 emissions during biomass collection includes shredding, baling and stacking[7,8]. **Table S4** summarizes the conversion rates of all technologies which are obtained from previous works[9–12]. The production cost, capital cost and CO_2 emissions for each technology are given in **Table S5**[9–14]. Production cost is directly proportional to the consumption level of input materials. Capital cost of each technology is calculated based on n-th plant cost analysis and linearized it with the piecewise linearization approximation presented in Appendix A. Finally, the traveling cost and CO_2 emissions due to transportation are given in **Table S6**[15]. Note that all costs are indexed to 2014 dollars and calculated based on dry mass basis.

Table S1: Latitude and longitude of farms and biorefineries[1]

Node	County	Latitude	Longitude
0	Origin Point	42.505721	-89.837117
Farm			
F1	Dane	43.182533	-89.219957
F2	Dane	43.182533	-89.632322
F3	Dane	42.960038	-89.219957
F4	Dane	42.960038	-89.632322
F5	Dodge	43.523213	-88.552815
F6	Dodge	43.523213	-88.856985
F7	Dodge	43.306746	-88.552815
F8	Dodge	43.306746	-88.856985
F9	Rock	42.580298	-88.925036
F10	Rock	42.580298	-89.221768
F11	Rock	42.756749	-88.925036
F12	Rock	42.756749	-89.221768
F13	Columbia	43.553870	-89.188120
F14	Columbia	43.553870	-89.543115
F15	Columbia	43.374457	-89.188120
F16	Columbia	43.374457	-89.543115
F17	Green	42.769265	-89.486714
F18	Green	42.769265	-89.720316
F19	Green	42.593569	-89.486714
F20	Green	42.593569	-89.720316
F21	Jefferson	43.109021	-88.659310
F22	Jefferson	43.109021	-88.892769
F23	Jefferson	42.932062	-88.659310
F24	Jefferson	42.932062	-88.892769
Biorefinery			
BA	Dane	42.902712	-89.434257
BB	Columbia	43.319661	-89.042714

Table S2: Biomass availability for each time period[2–4]

(a) Corn stover

Node	Period			
	Spring	Summer	Fall	Winter
F1	0	24,220	10,380	0
F2	0	24,220	10,380	0
F3	0	24,220	10,380	0
F4	0	24,220	10,380	0
F5	0	23,468	10,058	0
F6	0	23,468	10,058	0
F7	0	23,468	10,058	0
F8	0	23,468	10,058	0
F9	0	20,808	8,918	0
F10	0	20,808	8,918	0
F11	0	20,808	8,918	0
F12	0	20,808	8,918	0
F13	0	19,513	8,363	0
F14	0	19,513	8,363	0
F15	0	19,513	8,363	0
F16	0	19,513	8,363	0
F17	0	8,416	3,607	0
F18	0	8,416	3,607	0
F19	0	8,416	3,607	0
F20	0	8,416	3,607	0
F21	0	10,974	4,703	0
F22	0	10,974	4,703	0
F23	0	10,974	4,703	0
F24	0	10,974	4,703	0

(b) Switchgrass

Node	Period			
	Spring	Summer	Fall	Winter
F1	0	7,712	3,305	0
F2	0	7,712	3,305	0
F3	0	7,712	3,305	0
F4	0	7,712	3,305	0
F5	0	2,927	1,254	0
F6	0	2,927	1,254	0
F7	0	2,927	1,254	0
F8	0	2,927	1,254	0
F9	0	5,142	2,204	0
F10	0	5,142	2,204	0
F11	0	5,142	2,204	0
F12	0	5,142	2,204	0
F13	0	2,527	1,083	0
F14	0	2,527	1,083	0
F15	0	2,527	1,083	0
F16	0	2,527	1,083	0
F17	0	5,020	2,151	0
F18	0	5,020	2,151	0
F19	0	5,020	2,151	0
F20	0	5,020	2,151	0
F21	0	1,595	683	0
F22	0	1,595	683	0
F23	0	1,595	683	0
F24	0	1,595	683	0

Table S3: Cost and CO_2 emissions during biomass collection at farms[5–8]

Compound	Total Cost ($/dry t)	CO_2 Emission (kg CO_2eq/dry t)
CS	33.9	27.0
SG	55.4	16.0

Table S4: Conversion for each technology[9–12]

Compound		Technology	Conversion (t output/t input or L output/t input*)
Input	Output		
CS	CS-AP	AFEX-DD	0.99
SG	SG-AP	AFEX-DD	0.99
CS	CS-P	AFEX	0.99
SG	SG-P	AFEX	0.99
CS	CS-A	AFEX	0.99
SG	SG-A	AFEX	0.99
CS-AP/CS-P/CS-A	Ethanol	SSCF	280/280/278*
SG-AP/SG-P/SG-A	Ethanol	SSCF	283/283/281*
CS-AP/CS-P/CS-A	Ethanol	SHCF	280/280/278*
SG-AP/SG-P/SG-A	Ethanol	SHCF	283/283/281*

Table S5: Production cost, capacity cost and CO_2 emission for each technology[9–14]

Technology	Unit Production Cost ($/dry t)	Capital Cost Reference (10^6 $)	Capital Cost Reference Capacity (dry t/d)	CO_2 Emission (kg CO_2eq/dry t)
AFEX-DD	30.8	8.1	200	0.1
DD	15.2	3.0	200	0
AFEX	12.2	34.0	2,000	0.1
SSCF	67.7	381.3	2,000	288
SHCF	67.7	378.0	2,000	288

Table S6: Cost and CO_2 emission due to transportation[15]

		Cost		CO_2 Emission	
Arc	Compound	Constant ($/dry t)	Variable ($/dry t-km)	Constant (kg CO_2eq/dry t)	Variable (kg CO_2eq/dry t-km)
$j \rightarrow k/j \rightarrow l$	CS/SG	10.7	0.19	115.9	1.2
$k \rightarrow l$	CS-P/SG-P	4.5	0.06	62.7	0.7
	CS-AP/SG-AP	3.6	0.06	28.2	0.7

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