Design of Sustainable Product Systems and Supply Chains with Life Cycle Optimization based on Functional Unit: General Modeling Framework, MINLP Algorithms and Case Study on Hydrocarbon Biofuels

Dajun Yue, Min Ah Kim, Fengqi You*

Department of Chemical and Biological Engineering, Northwestern University, Evanston, IL 60208

Page: 30

Number of words: 6,688

Figures: 11

Tables: 3

* Corresponding author. Email: you@northwestern.edu

Supporting Information

Model Formulation for Case Study

In this section, we present the life cycle optimization model. Since the model is a modification and simplification of the one proposed in the work by You and Wang[21], equations will not be explained in detail in this paper. For clarity, all the parameters are denoted in upper-case words, and all the variables are denoted in lower-case words. A notation of indices, sets, parameters and variables can be found in the following Notations section. Note that the equation numbering continues from that in the main text.

As given by (28), the economic objective is to minimize the unit cost per GEG liquid fuel product, which is defined as the total annualized cost divided by the standard quantity of functional unit.

$$\min\ ftc = \frac{C_{capital} + C_{acquisition} + C_{distribution} + C_{production} + C_{transportation} - C_{incentive}}{\sum_{d \in D} \sum_{p \in P} \varphi_p sold_{d,p}} \tag{28}$$

As given by (29), the environmental objective is to minimize the environmental impact per GEG liquid fuel product, which is defined as the total emissions divided by the standard quantity of functional unit.

$$\min\ fte = \frac{E_{acquisition} + E_{distribution} + E_{production} + E_{transportation} - E_{sequestration}}{\sum_{d \in D} \sum_{p \in P} \varphi_p sold_{d,p}} \tag{29}$$

Equations (30) - (35) calculate the components of the total annualized cost.

$$C_{capital} = \frac{IR\left(1+IR\right)^{NY}}{\left(1+IR\right)^{NY}-1}\left(\sum_{j \in J} tcapj_j + \sum_{k \in K} tcapk_k + \sum_{l \in L} tcapl_l\right) \tag{1}$$

$$C_{acquisition} = \sum_{b \in B} \sum_{i \in I} CBM_{b,i} \cdot bmp_{b,i} \tag{2}$$

$$C_{distribution} = \sum_{d \in D} \sum_{p \in P} CLD_{d,p} \cdot sold_{d,p} \tag{3}$$

$$
\begin{aligned}
C_{production} &= \sum_{j\in J} tcfpj_j + \sum_{k\in K} tcfpk_k + \sum_{l\in L} tcfpl_l \\
&+ \sum_{j\in J}\sum_{p\in P}\sum_{q\in Q} CPJ_{j,q}\varphi_p wpj_{j,p,q} \\
&+ \sum_{k\in K}\sum_{b\in B}\sum_{q'\in Q} CPK_{k,q'}\rho_b wbk_{b,k,q} \\
&+ \sum_{l\in L}\sum_{p\in P}\sum_{q''\in Q} CPL_{l,q''}\varphi_p wpl_{l,p,q''}
\end{aligned} \tag{4}
$$

$$
\begin{aligned}
C_{transportation} &= \sum_{b\in B}\sum_{i\in I}\sum_{j\in J}\left(DFCB_b + DVCB_b DSIJ_{i,j}\right) fij_{b,i,j} \\
&+ \sum_{b\in B}\sum_{i\in I}\sum_{k\in K}\left(DFCB_b + DVCB_b DSIK_{i,k}\right) fik_{b,i,k} \\
&+ \sum_{g\in G}\sum_{k\in K}\sum_{l\in L}\left(DFCG_g + DVCG_g DSKL_{k,l}\right) fkl_{g,k,l} \\
&+ \sum_{d\in D}\sum_{j\in J}\sum_{p\in P}\left(DFCP_p + DVCP_p DSJD_{d,j}\right) fjd_{d,j,p} \\
&+ \sum_{d\in D}\sum_{l\in L}\sum_{p\in P}\left(DFCP_p + DVCP_p DSLD_{d,l}\right) fld_{d,l,p}
\end{aligned} \tag{5}
$$

$$
C_{incentive} = \frac{IR(1+IR)^{NY}}{(1+IR)^{NY}-1}\left(\sum_{j\in J} incj_j + \sum_{k\in K} inck_k + \sum_{l\in L} incl_l\right) + \sum_{d\in D}\sum_{p\in P}\sum_{t\in T} INCV_{d,p}\cdot sold_{d,p} \tag{6}
$$

Equations (36) - (40) calculate the components of the total GHG emissions.

$$
E_{acquisition} = \sum_{b\in B}\sum_{i\in I} EBM_{b,i}\cdot bmp_{b,i} \tag{7}
$$

$$
E_{distribution} = \sum_{d\in D}\sum_{p\in P} ELD_{d,p}\cdot sold_{d,p} \tag{8}
$$

$$
\begin{aligned}
E_{production} &= \sum_{j\in J}\sum_{p\in P}\sum_{q\in Q} EPJ_{j,p}\varphi_p wpj_{j,p,q} \\
&+ \sum_{b\in B}\sum_{k\in K}\sum_{q'\in Q} EPK_{k,q'}\rho_b wbk_{b,k,q'} \\
&+ \sum_{l\in L}\sum_{p\in P}\sum_{q''\in Q} EPL_{l,q''}\varphi_p wpl_{l,p,q''}
\end{aligned} \tag{9}
$$

$$E_{transportation} = \sum_{b\in B}\sum_{i\in I}\sum_{j\in J}\left(ETRB_b DSIJ_{i,j}\right) fij_{b,i,j}$$
$$+\sum_{b\in B}\sum_{i\in I}\sum_{k\in K}\left(ETRB_b DSIK_{i,k}\right) fik_{b,i,k}$$
$$+\sum_{g\in G}\sum_{k\in K}\sum_{l\in L}\left(ETRG_g DSKL_{k,l}\right) fkl_{g,k,l} \quad (10)$$
$$+\sum_{d\in D}\sum_{j\in J}\sum_{p\in P}\left(ETRP_p DSJD_{d,j}\right) fjd_{d,j,p}$$
$$+\sum_{d\in D}\sum_{l\in L}\sum_{p\in P}\left(ETRP_p DSLD_{d,l}\right) fld_{d,l,p}$$

$$E_{sequestration} = \sum_{b\in B}\sum_{i\in I} ESCS_b \cdot bmp_{b,i} \quad (11)$$

Constraints (41) - (44) correspond to the biomass feedstock supply system.

$$bmp_{b,i} \le BA_{b,i}, \quad \forall b\in B, i\in I \quad (12)$$

$$bmp_{b,i} = \sum_{j\in J} fij_{b,i,j} + \sum_{k\in K} fik_{b,i,k}, \quad \forall b\in B, i\in I \quad (13)$$

$$\sum_{b\in B} \frac{\rho_b \cdot fij_{b,i,j}}{1-MC_b} \le WCIJ_{i,j}, \quad \forall i\in I, j\in J \quad (14)$$

$$\sum_{b\in B} \frac{\rho_b \cdot fik_{b,i,k}}{1-MC_b} \le WCIK_{i,k}, \quad \forall i\in I, k\in K \quad (15)$$

Constraints (45) - (55) correspond to the integrated biorefineries.

$$\sum_{i\in I} fij_{b,i,j} = \sum_{q\in Q} wbj_{b,j,q}, \quad \forall b\in B, j\in J \quad (16)$$

$$\sum_{q\in Q} wpj_{j,p,q,t} = \sum_{d\in D} fjd_{d,j,p,t}, \quad \forall j\in J, p\in P \quad (17)$$

$$\sum_{q\in Q}\sum_{r\in R} x_{j,q,r} \le 1, \quad \forall j\in J \quad (18)$$

$$\sum_{j\in J}\sum_{r\in R} x_{j,q,r} \le NJ_q, \quad \forall q\in Q \quad (19)$$

$$PRJ_{j,q,r-1} x_{j,q,r} \le capj_{j,q,r} \le PRJ_{j,q,r} x_{j,q,r}, \quad \forall j \in J, q \in Q, r \in R \tag{20}$$

$$tcapj_j = \sum_{q \in Q} \sum_{r \in R} \left[\begin{array}{l} CRJ_{j,q,r-1} \cdot x_{j,q,r} \\ + \left(capj_{j,q,r} - PRJ_{j,q,r-1} \cdot x_{j,q,r} \right) \left(\dfrac{CRJ_{j,q,r} - CRJ_{j,q,r-1}}{PRJ_{j,q,r} - PRJ_{j,q,r-1}} \right) \end{array} \right], \quad \forall j \in J \tag{21}$$

$$tcfpj_j = \sum_{q \in Q} \left\{ CFJ_{j,q} \sum_{r \in R} \left[\begin{array}{l} CRJ_{j,q,r-1} \cdot x_{j,q,r} \\ + \left(capj_{j,q,r} - PRJ_{j,q,r-1} \cdot x_{j,q,r} \right) \left(\dfrac{CRJ_{j,q,r} - CRJ_{j,q,r-1}}{PRJ_{j,q,r} - PRJ_{j,q,r-1}} \right) \end{array} \right] \right\}, \quad \forall j \in J \tag{22}$$

$$incj_j \le INCM \sum_{q \in Q} \sum_{r \in R} x_{j,q,r}, \quad \forall j \in J \tag{23}$$

$$incj_j \le INCP \cdot tcapj_j, \quad \forall j \in J \tag{24}$$

$$\theta_{j,q} \sum_r capj_{j,q,r} \le \sum_{p \in P} \varphi_p wpj_{j,p,q,t} \le \sum_r capj_{j,q,r}, \quad \forall j \in J, q \in Q \tag{25}$$

$$wpj_{j,p,q} = \sum_b \alpha_{b,p,q} \cdot wbj_{b,j,q}, \quad \forall j \in J, p \in P, q \in Q \tag{26}$$

Constraints (56) - (66) correspond to the preconversion facilities.

$$\sum_{i \in I} fik_{b,i,k} = \sum_{q' \in Q} wbk_{b,k,q'}, \quad \forall b \in B, k \in K \tag{27}$$

$$\sum_{q' \in Q} wgk_{g,k,q'} = \sum_{l \in L} fkl_{g,k,l}, \quad \forall g \in G, k \in K \tag{28}$$

$$\sum_{q' \in Q} \sum_{r \in R} y_{k,q',r} \le 1, \quad \forall k \in K \tag{29}$$

$$\sum_{k \in K} \sum_{r \in R} y_{k,q',r} \le NK_{q'}, \quad \forall q' \in Q \tag{30}$$

$$PRK_{k,q',r-1} \cdot y_{k,q',r} \le capk_{k,q',r} \le PRK_{k,q',r} \cdot y_{k,q',r}, \quad \forall k \in K, q \in Q, r \in R \tag{31}$$

$$tcapk_k = \sum_{q'\in Q}\sum_{r\in R}\left[\begin{array}{l} CRK_{k,q',r-1}\cdot y_{k,q',r} \\ +\left(capk_{k,q',r} - PRK_{k,q',r-1}\cdot y_{k,q',r}\right)\left(\dfrac{CRK_{k,q',r} - CRK_{k,q',r-1}}{PRK_{k,q',r} - PRK_{k,q',r-1}}\right)\end{array}\right], \quad \forall k \in K \tag{32}$$

$$tcfpk_k = \sum_{q'\in Q}\left\{CFK_{k,q'}\sum_{r\in R}\left[\begin{array}{l} CRK_{k,q',r-1}\cdot y_{k,q',r} \\ +\left(capk_{k,q',r} - PRK_{k,q',r-1}\cdot y_{k,q',r}\right)\left(\dfrac{CRK_{k,q',r} - CRK_{k,q',r-1}}{PRK_{k,q',r} - PRK_{k,q',r-1}}\right)\end{array}\right]\right\}, \quad \forall k \in K \tag{33}$$

$$inck_k \le INCM \sum_{q'\in Q}\sum_{r\in R} y_{k,q',r}, \quad \forall k \in K \tag{34}$$

$$inck_k \le INCP \cdot tcapk_k, \quad \forall k \in K \tag{35}$$

$$\omega_{k,q}\sum_{r\in R} capk_{k,q',r} \le \sum_{b\in B}\rho_b \cdot wbk_{b,k,q'} \le \sum_{r\in R} capk_{k,q',r}, \quad \forall k \in K, q' \in Q \tag{36}$$

$$wgk_{g,k,q'} = \sum_{b\in B}\beta_{b,g,q'}\cdot wbk_{b,k,q'}, \quad \forall g \in G, k \in K, q' \in Q \tag{37}$$

Constraints (67) - (77) correspond to the intermediate upgrading facilities.

$$\sum_{k\in K} fkl_{g,k,l} = \sum_{q''\in Q} wgl_{g,l,q''}, \quad \forall g \in G, l \in L \tag{38}$$

$$\sum_{q''\in Q} wpl_{l,p,q''} = \sum_{d\in D} fld_{d,l,p}, \quad \forall l \in L, p \in P \tag{39}$$

$$\sum_{q''\in Q}\sum_{r\in R} z_{l,q'',r} \le 1, \quad \forall l \in L \tag{40}$$

$$\sum_{l\in L}\sum_{r\in R} z_{l,q'',r} \le NL_{q''}, \quad \forall q'' \in Q \tag{41}$$

$$PRL_{l,q'',r-1}\cdot z_{l,q'',r} \le capl_{l,q'',r} \le PRL_{l,q'',r}\cdot z_{l,q'',r}, \quad \forall l \in L, q \in Q, r \in R \tag{42}$$

$$tcapl_l = \sum_{q"\in Q}\sum_{r\in R}\left[\begin{array}{l} CRL_{l,q",r-1}\cdot z_{l,q",r} \\ +\left(capl_{l,q",r} - PRL_{l,q",r-1}\cdot z_{l,q",r}\right)\left(\dfrac{CRL_{l,q",r} - CRL_{l,q",r-1}}{PRL_{l,q",r} - PRL_{l,q",r-1}}\right)\end{array}\right], \quad \forall l \in L \tag{43}$$

$$tcfpl_l = \sum_{q"\in Q}\left\{CFL_{l,q"}\sum_{r\in R}\left[\begin{array}{l} CRL_{l,q",r-1}\cdot z_{l,q",r} \\ +\left(capl_{l,q",r} - PRL_{l,q",r-1}\cdot z_{l,q",r}\right)\left(\dfrac{CRL_{l,q",r} - CRL_{l,q",r-1}}{PRL_{l,q",r} - PRL_{l,q",r-1}}\right)\end{array}\right]\right\}, \quad \forall l \in L \tag{44}$$

$$incl_l \le INCM\sum_{q"\in Q}\sum_{r\in R} z_{l,q",r}, \quad \forall l \in L \tag{45}$$

$$incl_l \le INCP\cdot tcapl_l, \quad \forall l \in L \tag{46}$$

$$\eta_{l,q"}\sum_{r\in R} capl_{l,q",r} \le \sum_{p\in P}\varphi_p wpl_{l,p,q",t} \le \sum_{r\in R} capl_{l,q",r}, \quad \forall l \in L, q" \in Q \tag{47}$$

$$wpl_{l,p,q"} = \sum_{g\in G}\gamma_{g,p,q"}\cdot wgl_{g,l,q"}, \quad \forall l \in L, p \in P, q" \in Q \tag{48}$$

Constraints (78) - (80) correspond to the liquid fuel distribution system.

$$\sum_{j\in J} fjd_{d,j,p} + \sum_{l\in L} fld_{d,l,p} = sold_{d,p}, \quad \forall d \in D, p \in P \tag{49}$$

$$sold_{d,p} \le DEM^U_{d,p}, \quad \forall d \in D, p \in P \tag{50}$$

$$sold_{d,p} \ge DEM^L_{d,p}, \quad \forall d \in D, p \in P \tag{51}$$

In summary, the life cycle optimization model includes two objectives given in (28) and (29). The components of cost and environmental costs are given by (30) - (35) and (36) - (40), respectively. The major properties of the BTL supply chain are described by (41) - (80), including biomass feedstock availability, material balance relationship, conversion facility capacity, transportation link capacity, financial constraints, etc.

Notations

Sets

B	Set of biomass types indexed by b
D	Set of demand zones indexed by d
G	Set of intermediate products (e.g., bio-oil, bio-slurry) indexed by g
I	Set of harvesting sites indexed by i
J	Set of integrated biorefinery facilities indexed by j
K	Set of preconversion facilities indexed by k
L	Set of intermediate upgrading facilities indexed by l
P	Set of final products (e.g., gasoline, diesel) indexed by p
Q	Set of biomass conversion or liquid transportation fuels production technologies indexed by q, q', q''
R	Set of capacity levels of (pre)conversion facilities indexed by r

Parameters

$BA_{b,i}$	Available amount of biomass type b in harvesting site i
$CBM_{b,i}$	Farm-gate cost of biomass feedstock type b from harvesting site i
$CFJ_{j,q}$	Fixed annual O&M cost as the percentage of the total investment cost of integrated biorefinery j with technology q
$CFK_{k,q'}$	Fixed annual O&M cost as the percentage of the total investment cost of preconversion facility k with technology q'

$CFL_{l,q''}$	Fixed annual O&M cost as the percentage of the total investment cost of intermediate upgrading facility l with technology q''
$CLD_{d,p}$	Local distribution cost of unit quantity of fuel product p at demand zone d
$CPJ_{j,q}$	Net unit production cost per gallon of gasoline equivalent of liquid transportation fuel in integrated biorefinery j with technology q (after considering charcoal credit)
$CPK_{k,q'}$	Net unit production cost per dry ton of standard biomass in preconversion facility k with technology q' (after considering charcoal credit)
$CPL_{l,q''}$	Net unit production cost per gallon of gasoline equivalent of liquid transportation fuel in intermediate upgrading facility l with technology q'' (after considering charcoal credit)
$CRJ_{j,q,r}$	Total capital investment of integrated biorefinery j with technology q and capacity level r
$CRK_{k,q',r}$	Total capital investment of preconversion facility k with technology q' and capacity level r
$CRL_{l,q'',r}$	Total capital investment of intermediate upgrading facility l with technology q'' and capacity level r
$DEM^{L}_{d,p}$	Lower bound of the demand for fuel product p at demand zones d
$DEM^{U}_{d,p}$	Upper bound of the demand for fuel product p at demand zones d
$DFCB_{b}$	Distance fixed cost of biomass type b
$DFCG_{g}$	Distance fixed cost of intermediate type g

$DFCP_p$ Distance fixed cost of fuel product type p

$DSIJ_{i,j}$ Distance from harvesting site i to integrated biorefinery j

$DSIK_{i,k}$ Distance from harvesting site i to preconversion facility k

$DSJD_{d,j}$ Distance from integrated biorefinery j to demand zones d

$DSKL_{k,l}$ Distance from preconversion facility k to intermediate upgrading facility l

$DSLD_{d,l}$ Distance from intermediate upgrading facility l to demand zones d

$DVCB_b$ Distance variable cost of biomass type b

$DVCG_g$ Distance variable cost of intermediate type g

$DVCP_p$ Distance vaiable cost of fuel product type p

$EBM_{b,i}$ Emission due to cultivation and acquisition of unit quantity of biomass type b from harvesting site i

$ELD_{d,p}$ Emission due to local distribution of fuel product type p at demand zone d

$EPJ_{j,p}$ Emission of producing a gallon of gasoline equivalent of liquid transportation fuel in integrated biorefinery j with technology q

$EPK_{k,q'}$ Emission of processing a dry ton of standard biomass in preconversion facility k with technology q'

$EPL_{l,q''}$ Emission of producing a gallon of gasoline equivalent of liquid transportation fuel in intermediate upgrading facility l with technology q''

$ESCS_b$ Emission credit of soil carbon sequestration due to biomass type b

$ETRB_b$ Emission of transporting unit amount of biomass type b for unit distance

$ETRG_g$ Emission of transporting unit amount of intermediate type g for unit distance

$ETRP_p$ Emission of transporting unit amount of fuel product type p for unit distance

$INCM$ Maximum incentive that can be provided for the construction of biomass conversion facilities

$INCP$ Maximum percentage of the construction cost of biomass conversion facilities that can be covered by government incentive

$INCV_{d,p}$ Volumetric production incentive of fuel product type p sold to demand zone d

IR Discount rate

MC_b Moisture content (in weight) of biomass type b

NJ_q Maximum number of integrated biorefineries with technology q that can be constructed

$NK_{q'}$ Maximum number of preconversion facilities with technology q' that can be constructed

$NL_{q''}$ Maximum number of intermediate upgrading facilities with technology q'' that can be constructed

NY Project lifetime in terms of years

$PRJ_{j,p,r}$ Upper bound of the capacity (in terms of gallons of gasoline equivalent) of integrated biorefinery j with technology q and capacity level r

$PRK_{k,q',r}$ Upper bound of the capacity (in terms of dry tons of standard biomass) of preconversion facility k with technology q' and capacity level r

$PRL_{l,q'',r}$ Upper bound of the capacity (in terms of gallons of gasoline equivalent) of intermediate upgrading facility l with technology q'' and capacity level r

$WCIJ_{i,j}$ Weight capacity for the transportation of biomass from harvesting site i to integrated biorefinery j

$WCIK_{i,k}$ Weight capacity for the transportation of biomass from harvesting site i to preconversion facility k

$\alpha_{b,p,q}$ Yield of fuel product p converted from unit quantity of biomass type b at integrated biorefineries with technology q

$\beta_{b,g,q'}$ Yield of intermediate g converted from unit quantity of biomass type b at preconversion facilities with technology q'

$\gamma_{g,p,q''}$ Yield of fuel product p converted from unit quantity of intermediate type g at intermediate upgrading facilities with technology q''

$\theta_{j,q}$ Minimum production amount as a percentage of capacity for integrated biorefinery j with conversion technology q

$\eta_{l,q''}$ Minimum production amount as a percentage of capacity for intermediate upgrading facility l with technology q''

φ_p Gasoline-equivalent gallons of 1 gal of fuel product p

ρ_b Mass quantity of standard dry biomass of 1 dry ton of biomass type b

Binary Variables

$x_{j,p,r}$ 0-1 variable, equal to 1 if an integrated biorefinery with technology q and capacity level r is located at site j

$y_{k,q',r}$ 0-1 variable, equal to 1 if a preconversion facility with technology q' and capacity level r is located at site k

$z_{l,q'',r}$ 0-1 variable, equal to 1 if an intermediate upgrading facility with technology q'' and capacity level r is located at site l

Continuous Variables (0 to $+\infty$)

$bmp_{b,i}$ Amount of biomass type b procured from harvesting site i

$capj_{j,q,r}$ Annual production capacity (in terms of gallons of gasoline equivalent) of integrated biorefinery j with technology q and capacity level r

$capk_{k,q',r}$ Annual production capacity (in terms of dry tons of standard biomass) of preconversion facility k with technology q' and capacity level r

$capl_{l,q'',r}$ Annual production capacity (in terms of gallons of gasoline equivalent) of intermediate upgrading facility l with technology q'' and capacity level r

$fij_{b,i,j}$ Amount of biomass type b shipped from harvesting site i to biorefinery j

$fik_{b,i,k}$ Amount of biomass type b shipped from harvesting site i to preconversion facility k

$fjd_{d,j,p}$ Amount of fuel product type p shipped from biorefinery j to demand zones d

$fkl_{g,k,l}$ Amount of intermediate type g shipped from preconversion facility k to intermediate upgrading facility l

$fld_{d,l,p}$ Amount of fuel product type p shipped from intermediate upgrading facility l to demand zones d

ftc Unit cost per functional unit of operating the biofuel supply chain

fte Unit GHG emission per functional unit of operating the biofuel supply chain

$incj_j$ Incentive received for the construction of integrated biorefinery j

$inck_k$	Incentive received for the construction of preconversion facility k
$incl_l$	Incentive received for the construction of intermediate upgrading facility l
$sold_{d,p}$	Amount of fuel product type p sold to demand zones d
$tcapj_j$	Total capital investment of installing integrated biorefinery j
$tcapk_k$	Total capital investment of installing preconversion facility k
$tcapl_l$	Total capital investment of installing intermediate upgrading facility l
$tcfpj_j$	Fixed annual production cost of integrated biorefinery j
$tcfpk_k$	Fixed annual production cost of preconversion facility k
$tcfpl_l$	Fixed annual production cost of intermediate upgrading facility l
$wbj_{b,j,q}$	Amount of biomass type b used for the production of liquid transportation fuel through conversion technology q in integrated biorefinery j
$wbk_{b,k,q'}$	Amount of biomass type b used for the production of biofuels through conversion technology q' in preconversion facility k
$wgk_{g,k,q'}$	Amount of intermediate type g produced through conversion technology q' in preconversion facility k
$wgl_{g,l,q''}$	Amount of intermediate type g converted to liquid transportation fuel through conversion technology q'' in intermediate upgrading facility l
$wpj_{j,p,q}$	Amount of fuel product type p produced through conversion technology q in integrated biorefinery j

$wpl_{l,p,q''}$ Amount of fuel product type p produce through conversion technology q'' in intermediate upgrading facility l