CHEMICAL ENGINEERINGTRANSACTIONS

VOL. 70, 2018

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors:Timothy G. Walmsley, Petar S.Varbanov, Rongxin Su, Jiří J.Klemeš
Copyright © 2018, AIDIC ServiziS.r.l.
ISBN978-88-95608-67-9; **ISSN** 2283-9216

DOI: 10.3303/CET1870049

Multi-Period Model of Sustainable Integrated Hybrid First and Second Generation Bioethanol Supply Chains

Boyan B. Ivanov*, Yunzile R. Dzhelil, Evgenij I. Ganev, Dragomir G. Dobruzhaliev

Institute of Chemical Engineering, Bulgarian Academy of Sciences, Akad. G. Bontchev, Str., 103, 1113 Sofia, Bulgaria
bivanov1946@gmail.com

This paper focuses on design of Integrated Bioethanol Supply Chain (IBSC) model that would account for economic, environmental and social aspects of sustainability. A mixed integer linear programming model is proposed to design an optimal IBSC. The model uses the delivered feedstock cost, energy consumption, and GHG emissions as system performance criteria. The efficiency of proposed supply chain design model is proved on a Bulgarian case study for biofuel production as the biomass supply chain is considered. The obtained from the design results have shown that the optimal BG IBSC configuration for 2020 includes 7 bioethanol plants and 4 plants for solid waste utilization. To meet the consumption needs of biofuel by 2020, the hybrid bioethanol plants should use mostly as raw materials wheat straw and corn cobs, which are available.

1. Introduction

Biofuel production and use is promoted worldwide. Its use could potentially reduce emissions of greenhouse gases and the need for fossil fuels (IEA, 2007). Accordingly, the European Union has imposed a mandatory target of 10 % biofuel production by the year 2020 (European Communities, Commission, 2003). Biofuels are produced from biomass feedstocks. Their use for energy purposes has the potential to provide important benefits. Burning biofuel releases as much CO_2 as the amount that has been absorbed by the biomass in its formation. Another advantage of biomass is its availability in the world due to its variety of sources. Despite its advantages, increasing quantities of biofuels to achieve EC objectives is accompanied by growing quantities of waste products. These wastes are related to the biofuels lifecycle from crop cultivation, transportation, and production up to distribution and use. The main liquid biofuels are bioethanol and biodiesel. Depending on the raw material used, production is considered in two generations.

The first generation used as feedstock crops containing sugar and starch to produce bioethanol (Rosegrant et al., 2006). In the production of bioethanol, the advantage of these materials is that they can be grown on contaminated and saline soils, as the process does not affect the fuel production. The drawback is that they raise issues related to their competitiveness in the food sector. Excessive use of fertilizers, pesticides and chemicals to grow them also leads to accumulation of pollutants in groundwater that can penetrate into water courses and thus degrade water quality.

Referring to the second generation, bioethanol is produced by using as raw material waste biomass (agricultural and forest waste) (Heungjo et al., 2011), i.e. lignocellulose which is transformed into a valuable resource as bioethanol.

The main technologies for production of bioethanol are fermentation, distillation and dehydration (Akgul et al., 2011). The wastes of biofuels are divided into production and performance. The technological waste is produced mainly in generation of products that occur as waste. The management of such waste is related to their reduction, recovery and disposal.

The present study deals with the issue of designing an optimal Integrated Bioethanol Supply Chains (IBSC) model for waste management in the process of biofuel production and use. Tools have been developed for the formulation of a mathematical model for the description of the parameter, the restrictions and the goal function.

Please cite this article as: Ivanov B.B., Dzhelil Y.R., Ganev E.I., Dobruzhaliev D.G., 2018, Multi-period model of sustainable integrated hybrid first and second generation bioethanol supply chains , Chemical Engineering Transactions, 70, 289-294 DOI:10.3303/CET1870049

2. Problem statement

The problem addressed in this work can be formally stated, as follows: Given are a set of biofuel crops, e.g. grain and straw that can be converted to bioethanol. These include agricultural feedstock e.g. wheat, corn, and straw. A planning horizon for government regulations including manufacturing, construction and carbon tax is considered. An IBSC network superstructure including a set of harvesting sites and a set of demand zones, as well as the potential locations of a number of collection facilities and bio refineries are set. Data for biofuel crops production and harvesting are also given. For each demand zone, the biofuel demand is given, and the environmental burden associated with bioethanol distribution in the local region is known. For each transportation link, the transportation capacity, available transportation modes, distance, and emissions of each transportation type are known.

2.1 General Formulation of the Problem

The overall problem can be summarized, as follows:

- Optimal locations of biofuel production centres,
- Demand for petroleum fuel for each of the demand centres,
- The minimum required ratio between petroleum fuel and biofuel for blending,
- Biomass feedstock types and their geographical availability,
- Specific Green House Gas (GHG) emission factors of the biofuel life cycle stages,
- Potential areas where systems for utilization of solid waste from production can be installed.

The objectives are to minimize total cost of an IBSC by optimizing the following decision variables:

- Supply chain network structure,
- Locations and scales of bioethanol production facilities, solid waste utilization plants and biomass cultivation sites,
- Flows of each biomass type and bioethanol between regions,
- Modes of transportation for delivery of biomass and bioethanol,
- The GHG emissions for each stage in the life cycle,
- Supply strategy for biomass to be delivered to facilities,
- Distribution processes for biofuel to be sent to demand zones.

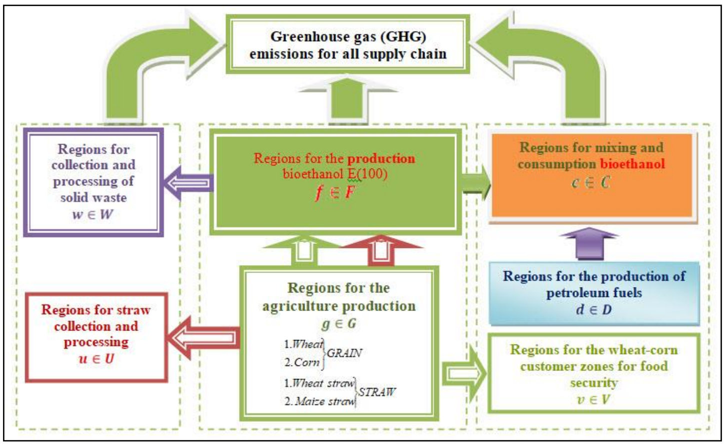

Figure 1: Superstructure of an IBSC

3. Model formulation

The role of the optimization model is to identify what combination of options is the most efficient approach to supply the facility. The problem for optimal location of bioethanol production plants and the efficient use of the available land is formulated as a MILP model with the following notation.

3.1 Mathematical model description

To start with the description of the MILP model, we first introduce the parameters, that are constant and known a priori, and the variables that are subject to optimization. Then we describe step by step the mathematical model by presenting the objective function and all constraints. First of all, the set of time intervals of the planning horizon $t = \{1,2,...,T\}$ is introduced.

In this article the mathematical model that is used in the network design is described. Before describing the mathematical model, the input parameters, the decision variables, and the sets, subsets and indices are listed below. The assessment of IBSC production and distribution of bioethanol will be made by environmental, economic and social criteria.

3.2 Model of total environmental impact of IBSC

The environmental impact of the IBSC is measured in terms of total GHG emissions ($kg\,CO_2 - eq$) stemming from supply chain activities and the total emissions are converted to carbon credits by multiplying them with the carbon price at the market.

The environmental objective is to minimize the total annual GHG emission resulting from the operations of the IBSC. The formulation of this objective is based on the field-to wheel life cycle analysis, which takes into account the following life cycle stages of biomass-based liquid transportation fuels:

- biomass cultivation, growth and acquisition,
- biomass transportation from source locations to facilities,
- transportation of bioethanol facilities to the demand zones,
- solid waste transportation from bioethanol facilities to utilization plants,
- local distribution of liquid transportation fuels in demand zones,
- emissions from bioethanol and gasoline usage.

Ecological assessment criteria will represent the total environmental impact at work on IBSC through the resulting GHG emissions for each time interval t . These emissions are equal to the sum of the impact that each of the stages of life cycle has on the environment. The GHG emission rate is defined as follows:

$$TEI_t = ELS_t + ELB_t + ELD_t + ETA_t + ETE_t + ETD_t + ETW_t + ETU_t + ETV_t + ECAR_t + ESW_t, \forall t \tag{1}$$

where

TEI_t	Total GHG impact at work on IBSC for each $t \in T$. [$kg\,CO_2 - eq\,d^{-1}$],
ELS_t	GHG impact of growing biomass,
ELB_t	GHG impact of production of bioethanol,
ELD_t	GHG impact of production of petroleum gasoline,
ETA_t	GHG impact of Transportation biomass,
ETE_t	GHG impact of Transportation bioethanol,
ETD_t	GHG impact of Transportation gasoline,
ETW_t	GHG impact of Transportation of solid waste,
ETU_t	GHG impact of Transportation of straw,
ETV_t	GHG impact of Transportation of wheat-corn for food security,
$ECAR_t$	GHG impact of Usage bioethanol and gasoline
ESW_t	GHG impact of utilization solid waste.

3.3 Model of total cost of an IBSC

The annual operational cost includes the biomass feedstock acquisition cost, the local distribution cost of final fuel product, the production costs of final products, and the transportation costs of biomass, and final products. In the production cost, we consider both the fixed annual operating cost, which is given as a percentage of the corresponding total capital investment, and the net variable cost, which is proportional to the processing amount. In the transportation cost, both distance-fixed cost and distance-variable cost are considered. The economic criterion will be the cost of living expenses to include total investment cost of bioethanol production facilities and operation of the IBDS. This price is expressed through the dependence is:

$$TDC_t = TIC_t + TIW_t + TPC_t + TPW_t + TTC_t + TTAXB_t - TL_t, \quad \forall t \tag{2}$$

where

TDC_t	Total cost of an IBSC for year [$\$\,year^{-1}$];

TIC_t	Total investment costs of production capacity of IBSC per year [$\$\ year^{-1}$];
TIW_t	Total investment costs of solid waste plants per year [$\$\ year^{-1}$];
TPC_t	Production cost for biorefineries [$\$\ year^{-1}$];
TPW_t	Production cost for solid waste plants [$\$\ year^{-1}$];
TTC_t	Total transportation cost of a IBSC [$\$\ year^{-1}$];
$TTAXB_t$	A carbon tax levied according to the total amount of CO_2 generated in the work of IBSC [$\$\ year^{-1}$];
TL_t	Government incentives for bioethanol production and use [$\$\ year^{-1}$].

3.4 Model of social assessment of an IBSC Job_t, [$Number\ of\ \ Jobs$]

The IBSC Social Assessment Model is to determine the expected total number of jobs created (Job_t) as a result of the operation of all elements of the system during its operation.

$$Job_t = NJ1_t + LT_t NJ2_t + LT_t NJ3_t,\ \ \forall t \tag{3}$$

where the components of Eq(3) are defined according to the relations for each time interval,

$NJ1_t$	number of jobs created during the installation of bioethanol refineries and solid waste plants,
$NJ2_t$	number of jobs created during the operation of bioethanol refineries and solid waste plants,
$NJ3_t$	number of jobs created by cultivation bioresources for bioethanol production,
LT_t	Duration of time intervals [$year$]

3.5 Restrictions

- Plants capacity limited by upper and lower constrains
- Limits on IBSC Flow Acceptability
- A limitation guaranteeing the regions' needs for straw for technical needs and utilization
- Solid waste plants capacity limited by upper and lower constrains
- Logical constrains
- Transport links
- Restriction for total environmental impact of all regions
- Mass balances between bioethanol plants and biomass regions
- Mass balances between bioethanol plants and customer zones
- Limitation guaranteeing crop rotation
- Model of constraints for energy balances
- Model of constraints for total cost of a BSC network

3.6 Economic objective function

The objective function associated with the minimization of the economic costs includes all the operating costs of the supply chain from purchase of the biomass feedstock to transportation of the final product, as well as the investment cost of biorefineries. The costs of the supply chain includes the cost of raw material, the transport of raw material to the facilities, the cost of transport to the biorefineries, the cost of transformation into bioethanol and the cost of final transport to the blending facilities. The economic objective is to minimize the total annual cost over the entire timeframe.

$$COST = \sum_{t \in T} \left(LT_t TDC_t \right) \tag{4}$$

3.7 Environmental objective function

The environmental objective function corresponds to the minimization of the entire environmental impact measured through the Eco indicator 99 method. The cumulative environmental impact of system performance defined as the amount of carbon dioxide equivalent generated over the whole life cycle and during its operation, is expressed by means of the equation:

$$ENV = \sum_{t \in T} \left(LT_t TEI_t \right) \tag{5}$$

3.8 Social objective function

As an estimate of the social impact of the system work, the exact coefficients that account for indirect jobs in the local economy are used. Then, the social impact (in terms of jobs) is determined according to the relationship $[\, Number\ of\ \ Jobs \,]$:

$$JOB = \sum_{t \in T} \left(LT_t Job_t \right) \tag{6}$$

4. Optimization problem formulation

The problem for the optimal design of an IBSC is formulated as a MILP model for the objective function of Minimizing cost. The task of determining the optimal location of facilities in the regions and their parameters is formulated as follows:

$$\left\{ \begin{array}{l} Find : X_t \left[\text{Decision variables} \right]^T \\ MINIMIZE \ \left\{ COST \right\} \rightarrow (Eq.4) \\ s.t. : \left\{ System\ of\ \ \mathrm{Re}\, strictions \right\} \end{array} \right\} \tag{7}$$

The problem is an ordinary MILP and can thus be solved using MILP techniques. The present model was developed in the commercial software GAMS (McCarl et al., 2008).

5. Case study: Potential bioethanol production in Bulgaria for 2016-2020

Two major types of biomass resources, Wheat and Corn for production of first generation and Wheat straw and Corn cobs of second generation bioethanol are used.

5.1 Model input data

Bulgaria has 27 regions. In this case study, each region is considered to be a feedstock production region, a potential location of a biorefinery facility and a demand zone. In other words, the biofuel supply chain network consists of 27 areas for feedstock production, 27 potential biorefinery locations, 27 demand zones, 4 potential solid waste utilization zones and 3 regions for the production of petroleum fuels. For the purposes of this study, data on population, cultivated area, as well as the free cultivated area, which in principle can be used for the production of energy crops for bioethanol production are taken from (Ivanov, Stoyanov, 2016). For 2016, the consumption of petroleum gasoline for transportation in the country which is 572,000 tons and for the next years it is: 2017→762,000 t, 2018→980,000 t, 2019→1,220,000 t, 2020→1,640,000 t. For the purposes of this study, it is assumed that the consumption of gasoline for each region is approximately proportional to its size.

5.2 Computational results and analysis

Table 1: Flow rate ($^{ton/day}$*) of biomass from growing region to bioethanol plants (Plant-R-XX) and solid waste from Plant-R-XX to solid waste plants (SW-R-XX) for 2020*

			Transport → TRACTOR				
	Energy crops	Wheat	Corn	Straw Wheat	Straw Corn	Flow path	Solid Waste
Plant-R-9	R-26 to R-9	1.00	1.00	500.72	1.00	Plant-R-9 to SW-R-26	258.24
Plant-R-8	R-12 to R-8	1.00	1.00	500.72	1.00	Plant-R-8 to SW-R-12	258.24
Plant-R-26	R-9 to R-26			500.72		Plant-R-26 to SW-R-26	258.24
	R-26 to R-26	1.00	1.00		1.00		
Plant-R-12	R-8 to R-12			364.03		Plant-R-12 to SW-R-12	258.24
	R-12 to R-12	1.00	1.00	136.68			
	R-22 to R-12				1.00		
Plant-R-27	R-4 to R-27			47.34		Plant-R-27 to SW-R-18	219.51
	R-27 to R-27			78.11			
	R-18 to R-27	1.00	1.00	298.48	1.00		
	R-2 to R-27				1.00		
Plant-R-18	R-27 to R-18	1.00		374.40		Plant-R-18 to SW-R-18	193.68
	R-22 to R-18				1.00		
	R-18 to R-18		1.00				
Plant-R-22	R-14 to R-22	1.00	1.00	393.66	38.02	Plant-R-22 to SW-R-14	258.24
	R-16 to R-22			70.04			

Table 2: Summary of computational results in case - Minimum Annualized Total Cost

Years	2016	2017	2018	2019	2020
Investment cost ($/year)$10^6$	1.862	2.793	3.531	4.462	6.248
Production cost ($/year)$10^6$	4.326	6.740	9.907	13.871	20.756
Transportation cost ($/year)$10^6$	3.165	4.457	6.086	8.317	12.854
Carbon tax levied in the work of IBSC ($/year)$10^6$	1.743	2.727	4.014	5.661	12.952
Government incentives for bioethanol production	-2.800	-4.371	-6.453	-9.079	-13.622
TOTAL COST ($/year)$10^6$	8.297	12.346	17.086	23.232	34.778
GHG emission to grow biomass	1422	1413	1978	1792	1792
GHG emission for production bioethanol and waste	64.220	100.238	147.930	208.018	312.033
GHG emission from transportation	228.289	211.298	311.615	266.253	277.120
GHG emission from biofuel usage	37.866	59.113	87.276	122.781	184.219
Total GHG emission for IBSC (kgCO2-eq./year)10^6	1752.468	1783.808	2525.148	2389.185	2565.732
Bioethanol produced from grain (ton/Year)	337	505	674	842	1179
Bioethanol produced from Straw and Maize cobs	32221	50323	74370	104730	157220
TOTAL BIOETHANOL PRODUCTION (ton/Year)	32558	50828	75044	105573	158400
TOTAL GAZOLINE NEED (ton/Year)	552015	730801	933938	1155199	1542775
Proportion Bioethanol/Gasoline (%)	6 %	7 %	8 %	9 %	10 %
Social function Job_t $(\,Number\ of\ Jobs\,)$	200	100	90	100	200

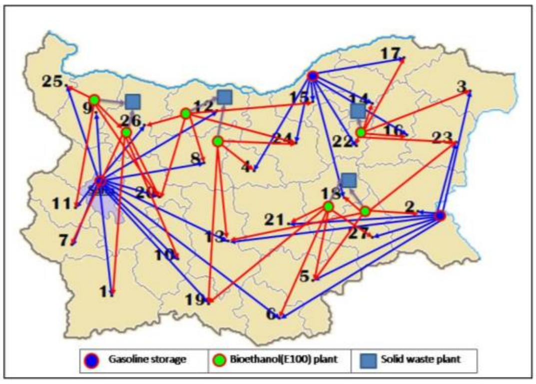

Figure 2: Optimal BG IBSC configuration for 2020

6. Conclusions

Analysing the results of the investigation, it is found that the available agricultural land in BG is giving an opportunity for producing sufficient amount of biological feedstock for production of the needed quantity of bioethanol in order to satisfy the BG needs and to reach the required quota of 10 % for liquid biofuel at 2020.

Acknowledgments

The study has been carried out by the financial support of National Science Fund, Ministry of Education and Science of the Republic of Bulgaria, Contract № ДН07-14/15.12.16.

References

Akgul O., Zamboni A., Bezzo F., Shah N., Papageorgiou L., 2011, Optimization-Based Approaches for Bioethanol Supply Chains, Industrial and Engineering Chemistry Research, 50, 4927-4938.

IEA, 2007, World energy outlook 2007, International Energy Agency, Paris, France.

Ivanov B., Stoyanov S., 2016, A mathematical model formulation for the design of an integrated biodiesel-petroleum diesel blends system, Energy, 99, 221-236.

European Communities, Commission 2003. Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003, on the promotion of the use of biofuels or other renewable fuels for transport.

Heungjo A.N., Wilbert E.W., Stephen W.S., 2011, Biofuel and petroleum-based fuel supply chain research: A literature review, Biomass and bioenergy, 35, 3763-3774.

McCarl B., Meeraus A., Eijk P., Bussieck M., Dirkse S., Steacy P., 2008, McCarl Expanded GAMS user Guide Version 22.9. GAMS Development Corporation, Washington DC, USA.

Rosegrant M.W., Msangi S., Sulser T., Valmonte-Santos R., 2006, Biofuels and the global food balance: bioenergy and agriculture promises and challenges, 2020 vision briefs 14, 3.