ISSN 1597-5835

OPTIMIZATION OF THE PETROLEUM PRODUCTSBLENDINGPROCESS IN KADUNA REFINING AND PETROCHEMICALS COMPANY (KRPC)

[1]SORETIRE,K.L. and [2]ABDULLAHI,A.T.

[1]Sarumedia Publishers Nigeria LTD,Kaduna, Nigeria,
Email:Soretire.lanrewaju@yahoo.com

[2]Department of Mechanical Engineering,Bayero University, Kano, Nigeria

Email: atarng299@gmail.com

ABSTRACT

General Algebraic Modeling System (GAMS) software was used to optimize the process of petroleum productsblending in KRPC. Optimum values of Regular and Premium blends of fuel were determined using Reformate, Light Straight Run (LSR) Naphtha, N-Butane, Fluidized Catalytic Cracking (FCC) gas and Alkylate as feed-stocks. Research Octane Number (RON) was used as a constraint in formulation of the optimization equation. The results show that at the initial stage of optimization, the profit recorded per month when 11,000 barrels of Premium fuel and 9,000 barrels of Regular fuel were blended was thirty nine million five hundred and ninety two thousand, eight hundred and twenty nine naira (₦39,592,829.00). However, a much higher profit margin of one hundred and seventeen million, three hundred and fifteen thousand, three hundred and sixty naira (₦117,315,360.00) was predicted when 29,500 barrels of Premium fuel and 12,000 barrels of Regular fuel were blended, an astronomical increase of 296%, proving the need for using linear programming in solving productionproblem in KRPC.

KEYWORDS: Optimization; Regularfuel; Premium fuel; GAMS software;Feedstock blending.

1.0 INTRODUCTION

Optimization is an integral part of engineering and is used by engineers (both practically and mathematically) to design new process/equipment, improve existing process, and optimize process operations (Edgar and Himmeblau, 1988).The refining industry is one of the early adaptors of linear programming (LP) to address its planning and optimization needs (Favennec, 2001).To derive operational efficiency, major refining companies are now putting increased focus on integrated processing, good refinery planning and scheduling to improve communication and total plant operation. More emphasis should therefore be put on enhancing the crude selection process, achieving immediate value from blend optimization, optimizing one to three months production planning activities and standardizing crude and refinery scheduling(Stommel et al., 2007).The planning and utilization of product capacity is one of the most important responsibilities of a Manager in the manufacturing industry in general and petroleum refineries in particular. Planning of petroleum refineries typically encompasses different areas, including oil management, process

ISSN 1597-5835

unit optimization and product blending (Al-Qahani et al., 2008).Production planning is an essential tool in today's petroleum refining industry. It aids in decision making and resource allocation to achieve business objectives through optimal production, sales and inventory management (Alattas et al., 2011).The work is aimed at optimization of Regular and Premiumfuels blending processes in Kaduna Refining and Petrochemical Company which will aid effective production of the products.

2.0 LITERATURE REVIEW

Petroleum refinery production planning has been widely studied and reported in various research literatures. Inventory management in gasoline blending optimization was discussed by Bodington (1992). Coxhead (1994) identified several applications of planning models in refinery operations, such as crude selection, crude allocation for multiple refineries and operations planning. The availability of Linear Programming (LP) based commercial software for refinery production planning such as Process Industry Modeling System (PIMS), allowed the development of general production plans for a whole Refinery (Pelham and Pharris, 1996)

The major advances in this area were based on model refinement, notably the use of non Linear Programming as in Picaseno – Gamiz (1989). The deterministic programming models, such as Linear Programming (LP), Mixed Integer Linear Programming (MILP) and Non Linear Programming (NLP), have been used for most Refinery production planning (Moro et al.,1998; Pinto et al., 2000; andJoly et al., 2002). Neiro and Pinto (2004) proposed a general frame work for modeling operational planning of petroleum supply chain. They developed different scenarios to investigate the effect of catastrophic failure and different environmental regulation changes on the performance of refineries. The Research work was carried out using(Commercial Planning Software) ASPEN PIMS. Alabi and Castro (2009) studied large scale integrated refinery planning problems.Zhang et al. (2007) proposed an effective MILP model to maximize the overall profit during oil refinery production planning system for better energy efficiency. Okopi and Salihi (2009) proposed linear programming model using MATHCAD to determine optimum product blending schedules.Joly (2012) reported that intelligent production planning and scheduling are of paramount importance to ensure refinery profitability, logistic reliability and safety at the local and corporate levels.

2.1 Optimization in Refining

Optimization can take place at many levels in a company, ranging from a complex combination of units to individual pieces of equipment, subsystem in a piece of equipment or even smaller entities (Beveridge and Schecter, 1970).Every Linear Programming is used as initial solution point for the model iteration until a satisfactory criterion is obtained. Boundary constraint was added to determine feasibility of the model. Many improvement and solution algorithms were developed to accommodate bigger and more complex problems (Ladson and Waren, 1983)

ISSN 1597-5835

The inaccurate and inconsistent results from the use of linear blending led to development of many techniques to handle non-linearities(De witt et al, 1989). One of the main challenges that inspired more research in the area of refining was blending or pooling problem (Bodington and Baker, 1992).Many refinery problems such as refining planning, crude oil transportation, final product shipping and profitability improvement are now addressed with algorithms based on mathematical models (Pinto et al., 2000). The petroleum industry has invested considerable resources in developing sophisticated mathematical programming models to help planners provide overall planning schemes for refinery operation, crude oil evaluation and other related tasks (Al-Qahani and El-Kamel., 2008).

3.0 MATERIALS AND METHODS

3.1 Materials

3.1.1 Blending Optimization Process in KRPC: Blending involves combining refinery feedstocks to enable the products meet certain quality specification. Formerly the products were pumpedupstream into storage or running tanks but the demands for petroleum products has forced the refineries to reduce the sizes of thetank. The refinery generates several streams that are blended in order to specify commercial products of different grades that must satisfy market demands.

The blending of Premium and Regular gasoline, the two grades of gasoline produced in KRPC, were considered as the blending model and Research Octane Number (RON), Motor Octane Number (MON)andReid Vapour Pressure(RVP)were used as framing quality constraints in the blending optimization.

The problem is based on acase study of KRPC in which Regular and Premium gasoline are to be blended simultaneously. Generally, the feed-stocksused in refineries all over the world are the same but the formulation is based on the environmental factors and demand targets. It is assumed that simulations take place for blending of the feedstock and there are two blenders working in parallel, one for Regular grade gasoline and the other for Premium grade gasoline. Both blenders produce batches which have minimum and maximum demand constraints (Table 1) and each grade has maximum available constraint (Table 2). It is assumed that all the feedstocks are coming to the blender through running constant volume feedstock tanks.The feed stocks to the blenders are;

1. Gasoline fraction from the catalyst reformer or Reformate;
2. Gasoline fraction from the Fluidized Catalytic Cracking unit (FCC Gas);
3. Light Straight Run(LSR) Naphtha;
4. Pure n-Butane from various units;
5. Gasoline fraction from the Alkylation unit.

ISSN 1597-5835

Table 1: Blended Gasoline Components

S/No	(Feed stock) Input	Cost(Naira)	Octane rating	Availability (bbl/day)
1	Reformate	98.00	94.00	8000
2	LSR Naphtha	120.00	70.00	6500
3	n-Butane	110.00	93.00	4000
4	FCC gas	131.00	92.00	6000
5	Alkylate	125.00	95.00	5000

Table 2: Blended Gasoline Demand and Expected Revenue in Nigeria

S/NO.	Product type	Cost(Naira)	Octane rating	Max Demand/Day (Barrels)
1	Premium	145	90	11000
2	Regular	160	100.00	9000

3.1.2 GAMS modelfor optimization of problems: GAMSis a programming language that provides a flexible framework for formulating and solving linear, non-linear and mixed integer optimization problems. Among other attributes, its syntax allows for declaring associations among variables, constants and constraints in the form of sets. It provides a wide array of solutions to optimize a variety of petroleum problems including LPs, NLPs and MINLPs.A GAMS model of an optimization problem will be written independent of the type of solver to be used in solving it. The following steps are involved.

i. Stating the linear problem;
ii. Creating accurate GAMS model of a mathematical problem;
iii. Solving the model by running it;
iv. GAMS solves the problem otherwise reports errors in the modeling;
v. The next step is manipulation and interpretation of the solver outputs.

3.2 Methods

There is need to determine how much of each input component need to be blended into Premium and Regular type of gasoline. Thus the total amounts of Premium fuel (P_x) and Regular fuel (R_x) produced per dayare made up of the sum of blending components (Feedstocks) which may be expressed as follows:-

$P_x = P_1 + P_2 + P_3 + P_4 + P_5$ and

$$R_x = R_1 + R_2 + R_3 + R_4 + R_5$$

As it was mentioned above RON is one of the key components, therefore its values will be enforced into the fuel to be produced per day as expressed in equations (1) and (2) below:

$$94\frac{P_1}{P_x} + 70\frac{P_2}{P_x} + 93\frac{P_3}{P_x} + 92\frac{P_4}{P_x} + 95\frac{P_5}{P_x} \geq 90 \ldots(1)$$

$$94\frac{R_1}{R_x} + 70\frac{R_2}{R_x} + 93\frac{R_3}{R_x} + 92\frac{R_4}{R_x} + 95\frac{R_5}{R_x} \geq 100 \ldots(2)$$

Where: P_i= Quantity of input component (feed stock) used to produce Premium gasoline;

ISSN 1597-5835

$i = 1,2,3,4,5; R_x =$ Quantity of feedstock used to produce Regular gasoline; x= $1, 2, 3, 4, and\ 5$.

Rewriting equations (1) and (2) will yield the following linear equations

$94P_1 + 70P_2 + 93P_3 + 92P_4 + 95P_5 \geq 90P_x$ ..(3)

$94R_1 + 70R_2 + 93R_3 + 92R_4 + 95R_5 \geq 100R_x$.(4)

3.2.1 The Objective Function: The objective is to maximize profit, avoid give away product and bad product. In other words to contribute towards a fixed cost and profit, the objective function can be expressed or stated mathematically from equations 1 and 2 as:

$$\text{Max}\, y = 145P_x + 160R_x - 98P_1 - 98R_1 - 120P_2 - 120R_2 - 110P_3 - 110R_3 - 131P_4 - 131R_4 - 125P_5 - 125R_5$$

According toMartand (2002), the equation may be written in the form:

$y = 145P_x + 160R_x - \{98(P_1 + R_1) +$ *120P2+R2+110P3+R3+131P4+R4+125(P5+R5)}* … (5)

Linear Programming equations can be generated and formulated as follows:-

Maximize from equation (5)

Constraints: There is a limited amount of Reformate, Naphtha, n-Butane, FCC gas and Alkylate. The inputs can be used in the generation of gasoline (PMS) i.e. Premium and Regular fuels. The available quantity of input can be expressed in the form of inequalities.

$$P_1 + R_1 \leq 8000; P_2 + R_2 \leq 6500;\ P_3 + R_3 \leq 4000; P_4 + R_4 \leq 6000; P_5 + R_5 \leq 5000;$$

The blending components used for production of Regular and Premium gasoline are Reformate, Naphtha, n-Butane, FCC gas and Alkylate. Therefore, the sum of these blending components gives the amount of Premium and Regular petroleum products produced.

$P_x = P_1 + P_2 + P_3 + P_4 + P_5$, and

$R_x = R_1 + R_2 + R_3 + R_4 + R_5$…(6)

$P_x \leq$Total amount of Premium fuel demand,

$R_x \leq$Total amount of Regular fuel demand,

$P_x \leq 11000, R_x \leq 9000$

There are upper bounds on the amounts of Premium and Regular fuels to be produced. The

$$y = 145P_x + 160R_x - 98P_1 - 98R_1 - 120P_2 - 120R_2 - 110P_3 - 110R_3 - 131P_4 - 131R_4 - 125P_5 - 125R_5$$

Subject to:

$$P_1 + R_1 \leq 8000; P_2 + R_2 \leq 6500; P_3 + R_3 \leq 4000;$$

$$P_4 + R_4 \leq 6000; P_5 + R_5 \leq 5000$$

$P_x = P_1 + P_2 \dots P_5$, $\quad P_x \leq 11000$

$R_x = R_1 + R_2 \dots R,$ $\quad R_x \leq 9000$

3.2.2 Solution to the linear optimization problems

Considering equation (5) and the constraints, the above equation can be modeled using GAMS as;

Variable Y;

Positive variables$P_x, P_1, P_2, P_3, P_4, P_5,$ $R_x, R_1, R_2, R_3, R_4, R_5$;

Equations:

Obj, Constr1, Constr2, Constr3, Constr4, Constr5, Constr6, Constr7, Constr8, Constr9;

$$Obj \dots Y = E = 145 * P_x + 160 * R_x - 98 * P_1 - 98 * R_1 - 120 * P_2 - 120 * R_2$$

$$-110 * P_3 - 110 * R_3 - 131 * P_4 - 131 * R_4 - 125 * P_5 - 125 * R_5;$$

$Constr1..P_1 + R_1 = L = 8000$

$Constr2..P_2 + R_2 = L = 6500;$

$Constr3..P_3 + R_3 = L = 4000;$

$Constr4..P_4 + R_4 = L = 6000;$

$Constr5..P_5 + R_5 = L = 5000;$

$Constr6..P_x = L = 11000;$

$Constr7..R_x = L = 9000;$

Constr8...
94*P1+70*P2+93*P3+92*P4+95*P5=G=90*Px;

Constr9..
94*R1+70*R2+93*R3+92*R4+95*R5=G=90*Rx;

Model Test LP_1 /ALL/

Solve Test LP_1 using LP maximizing Y;

RUN.

3.2.3 Sensitivity analysis Test

Variable Z;

Positive Variables: P_x, P_1, P_2, P_3, P_4, P_5, R_x, R_1, R_2, R_3, R_4, R_5;

Equations:

Obj, constr1, constr2, constr3, constr4, constr5, constr6, constr7, constr8, constr9;

$$\text{Obj}.\text{Z} = \text{E} = 145 * P_x + 160 * R_x - 98 * P_1 - 98 * R_1 - 120 * P_2 - 120 * R_2 - 110 * P_3 - 110 * R_3 - 131 * P_4 - 131 * R_4 - 125 * P_5 - 125 * R_5;$$

Constr1...$P_1 + R_1 = L = 5000$;

Constr2...$P_2 + R_2 = L = 6500$;

Constr3...$P_3 + R_3 = L = 4000$

Constr4...$P_4 + R_4 = L = 8000$

Constr5...$P_5 + R_5 = L = 6000$

Constr6...$P_x = L = 29500$;

Constr7...R_x= L =12000;

Constr8..$94 * P_1 + 70 * P_2 + 93 * P_3 + 92 * P_4 + 95 * P_5 = G = 90 * P_x;$

Constr9.. $94 * R_1 + 70 * R_2 + 93 * R_3 + 92 * R_4 + 95 * R_5 = G = 90 * R_x;$

Model TestLP$_1$ /ALL/ **RUN**

Solve TestLP$_1$ using L$_P$ Maximizing Z;

4.0 RESULTS AND DISCUSSION

4.1 Results

The profits obtained under different scenarios are summarized in Tables 3 and 4.

Table 3: Profit obtained when 11,000 barrels of Premium and 9,000 barrels of Regular fuels were blended

Product	Available quantity(Barrel)	Profit(Naira) per month
Premium Fuel	11000	21,483,302.00
Regular Fuel	9000	18,110,527.50
Total Profit per month	39,593,829.00	

Table 4: Profit obtained when 29,500 barrels of Premium and 12,000 barrels of Regular fuels were blended

Product	Available quantity (Barrel)	Profit (Naira)
Premium Fuel	29,5000	85,104,360.00
Regular Fuel	12,000	32,211,000.00
Total Profit per month	117,315,360.00	

3.1.2 Sensitivity Analysis and Originality of the Model: The sensitivity tests of the model were carried out by increasing or decreasing the quantity of the feedstocks as given below in Tables 5 and 6 respectively.

Sensitivity Test 1:In Table 5 the blended gasoline values of Alkylate and n-Butane were increased, the values of Reformate and FCC gas were reduced but Naphtha was kept constant.

Sensitivity Test 2:In Table 6 the blended gasoline value of Alkylate and FCC gas were increased while that of Reformate was decreased but Naphtha and n-Butane values remained the same.

Table 5 Blended gasoline components (Sensitivity Test 1)

Input	Cost(naira)	Octane No.	Availability (bbl/day)
Reformate	98.00	94.0	5000
LSR Naphtha	120.00	70.00	6500
N Butane	110.00	93.00	5000
FCC gas	131.00	92.00	3000
Alkylate	125.00	95.00	7000

Table 6: Blended gasoline components (Sensitivity Test 2)

Input	Cost(naira)	Octane No.	Availability (bbl/day)
Reformate	98.00	94.0	5000
LSR Naphtha	120.00	70.00	6500
N Butane	110.00	93.00	4000
FCC gas	131.00	92.00	8000
Alkylate	125.00	95.00	6000

4.2 Discussion of Results

The use of GAMS model in optimization of gasoline blending has shown that optimal yield can be achieved without rigorous and tedious calculations that arepresently used for production planning in KRPC. Currently,KRPC management projects production based on market demand datawhich they send to planning department for implementation without determining both long and short term planning consequences. Such forecast is usually associated with some uncertainty in demand.The uncertainty in demand can be as a result of any of the following.

a) Price of blending stock goes up in the market and the Refinery decides to divert or change the blending component to meet up customer demand;
b) Shut down of upstream whereby the feedstocks have to change the blending formulation, which calls for adoption of linear programming application to facilitate optimal scheduling for gasoline blending.
c) The initial solution provided for production of 11000 barrels of Premium fuel per day and 9000barrelsof Regular fuel per day from 400 barrels of N- Butane, 6000 barrels ofFCC gas, 5000 barrels of Alkylate, 8000barrels of Reformate and 6500 barrels of LSR Naptha gave a profit of₦39,593,829.00 per month.

The efficiency of the model was determined using a sensitivity test. In the test the quantity of blends produced were 29,500 barrels of Premium fuel and 12,000 barrels of Regular fuel. With these quantities of blends, the revenue was ₦185, 925,000.00 per month and production cost was₦68,609,640.00 giving a much higher profit margin of₦ 117,315,360.00 per month.

The results of the sensitivity test showed that if the quantity of blending stock was varied or increasedwith linear programming one can easily solve petroleum products processing problem, and the expected profit can be estimated. A possible remedy to linear programming problem is to update the model continuously based on plant data (Cuttler, 1999). On the other hand non-linear model has been built and single unit optimization has been implemented for different refinery operationsusing software packages such asASPENPLUS(ASPEN PIMS) and HYSIS.

However, there are obstacles in using LP for planning operation in the refinery. There is a continuous change of the crude quality, fluctuation in market demand and price and the operation of a refinery always changes. Such reactions which are non- linear will not easily and precisely be represented by linearprogramme.

Due to non-linear nature of refinery process, the linear programmes are simplified to speed up LP solution. Therefore, when operating conditions change, the linear model becomesinvalid.

This may lead to error in optimization results. In using LP it is assumed that all operations take place simultaneously without taking time and storage into consideration.

5.0 CONCLUSIONS

One of the guiding principles behind modern industry has always been achieving maximum possible profit. In this work the idea of optimization of feedstock (gasoline blending) involve maximizing the profit obtained by selling the blend, subject to blend quality specifications, feedstock availabilities and product demand by

customers. However, the constraint that was used in framing the optimization problem (equation) isuncertain to some degree simply because it was based on simulation not actual practical

.

demonstration.The optimization process adopted in this work gave a precise quality ofPremium and Regular fuel blends.The result of the study has shown that optimization of the fuel feedstocksblending processcan be achieved using GAMS software which is sensitive to change, taking into consideration RON and RVP.The results of the sensitivity Test using GAMS has the potential for producing296%profit compared with the current method of production planning used inKRPC.

REFERENCES

Agrawal, S.S. (1995).Integrated blending control optimization and planning Hydrocarbon Processing Vol.74 No.8 pp.129 – 139, Gulf, Houston, TxETAS-Unis.

Alabi, A. and Castro, J. (2009). Descent decomposition in large Scale integrated refinery planning, Computer and Operation Research vol. 36, pp. 2472-2483.

Alattas, A. M., Grossman, I. E. and Palou-Rivera, I. (2011). Integrating non-linear CDU models in refinery planning optimization, Ind. Eng. Chem. Res. Vol. 50 pp. 6860-6870

Alattas, A.M., Grossman, I. E. and Palou-Rivera, I. (2011). Refinery production planning Multi-period MNLP with Non-linear CDU Model, Chemical Engineering department, Carnegie Mellon University, Pittsburgh, U.S.A.

AL-Qahani, K. Y. and Elkamel, A. (2008) Planning and integration of refinery and petrochemical operations pp. 4-12,Wiley VchverlagGmbh& Co., KGA

Bethesda, M. (2011) An introduction to petroleum refining and production of ultra-low Sulphur gasoline and diesel fuel: The International Council on Clean Transportation, 20827-0404 www.mathpronic.com.

Beveridge, S. G. and Schechter, S.R. (1970) Optimization: Theory and Practice, McGraw-Hill, New York

Bodington, C. E., and Baker, T. E., (1992), A history of mathematic programming in the petroleum industry, Interface 20(4), 117-127, McGraw-Hill, Inc. New York

Brooke, A.D. and Kendrick, A. (2010). Users guide GAMS Development Co., Washington D.C.

Coxhead, R. E. (1994). Integrated planning and scheduling system for refinery industry in optimization industry, John Wiley and Sons, New York

De Witt, C. W., Lasdan, L. S., Warren, A. D., Brenner, D. A. and Mellem, S. A.(1989). Omega, An Improved gasoline blending system for Texaco, Interface 19, pp.85-101.

sEdgar, T. F. and D. M. Himmeblau, (1988). Optimization of chemical processes, McGraw Hill Inc., New York City, USA

Eilon, S. (1994), Elements of Production and Control, Universal Publishing Cooperation, Bombay

Favennec, J. (2001). History and development of dynamic programming, Control System Magazine, Nov.24

Flouda, C. A. and Paulegs, G. E., (1988). A mixed integer non-linear programming formulation for the synthesis of heat integrated distillation sequences, Computer and Chemical Engineering Vol. 12, pp. 531-542.

ISSN 1597-5835

Garry, J. H. and Handwork, G. E. (2007). Petroleum Refining Technology, 5th Edition, CRC, Press: Boca Raton, Florida.

Jain, P. K. (2009) Production planning and control, U-tube lecture from Mechanical and Industrial department, Indian Institute of learning, Rooke

Joly, M.; Moro, F. L. and Pinto, J. M. (2002). Planning and Scheduling for Petroleum Refineries using Mathematical programming, Brazilian Journal of Chem. Engineering Vol.19 pp. 207-228.

Joly, M. (2012). Refining production planning and scheduling, Brazilian Journal of Chemical Engineering, vol. 29 pp.371-384

Ladson, I. S. and Waren, A. D. (1983).Large scale non-linear programming computer applications operation research. Chemical Engineering, Vol. 28, pp.1029

Leffler, W .L. (1985). Petroleum refining for non-Technical person, Penn-Well Publishing

Martand, T. (2002). Industrial Engineering and Production Management, S. Chand & Company Ltd, Ram Nagar, New Delhi

Meyers, R. A. (2003).Handbook of Petroleum Refining Processes, 3rd Edition McGraw Hill.

Moro, L. F., Zanin, A. C. and Pinto, J. M, (1998). Planning Model for Refinery Diesel Production, Compt. Chemical Engineering, 22(suppl.) S1039-S1042.

Neiro, S. M.S. and Pinto, J. M. (2004). Multi-period Optimization for Production Planning of Refineries, Brazilian Journal of Chemical Engineering, Vol. 19, pp.262.

Okopi, A. M. and Salihi, A. (2009). Application of linear programming (LP) to a product blending problem in Kaduna Refining and Petrochemical Company limited, Journal of Engineering and Technology vol. 4, no.1

Parkash, S. (2003).Refining Processes Handbook. Gulf Professional Publishing Co.

Pelham, R. and Pharis, C. (1996). Refinery Operations and Control: A Future Vision, Journal on Hydrocarbon Processing Vol.75. no.7, pp. 89-94

Pinto, J. M., Joly, M. and Moro, L. F. L. (2000). A Planning Model for Petroleum Refinery, Brazilian Journal of Chemical Engineering, Vol. 17, pp.575.

Sote, K. (1993). Beyond the crude oil and gas reserves, pp102-134, Published by Lube Services Associates, 4/6A Fisman, Ikeja, Lagos (Nig).

Stommel, J. and Snell, B. (2007). Consider Better Practice for Refinery Operation, Hydrocarbon Processing, vol. 86, pp105-109. Published by Gulf Publishing Company.

Zhang, B.J. and Hua, B. (2007). Effective Mixed Integer Linear Programming Model for Refinery-wide Production Planning and Better Energy Utilization Clean Production, 15, pp.439-440