Model for Biomass-based Renewable Hydrogen Supply Chain

Irfan Ahmad Gondal*, Mukhtar Hussain Sahir*

*University of Engineering & Technology, 36A,Lalazar-I,Rawalpindi

‡ Corresponding Author; Irfan Ahmad Gondal,, University of Engineering & Technology, 36A,Lalazar-I,Rawalpindi, iffiag@yahoo.com, mukhtar.sahir@uettaxila.edu.pk

Received: 13.05.2012 Accepted:03.06.2012

Abstract- Pakistan though a developing country has a strong agricultural background which in turn leads to a strong resource of biomass. Further, the climate change scenario discourages the use of biomass as a combustion fuel. An integrated renewable hydrogen model has been developed based on biomass feed stocks as the raw input material for hydrogen production. It has been found that hydrogen can be produced at rates compatible with steam methane reforming, one of the most economical methods of generating hydrogen. However the model must have a strong statistical base and an up-to-date Geographical Information system to present accurate and logical results for effective energy planning.

Keywords- «keywords»

1. Introduction

Energy supply chains and modes of transport are very much interconnected with one another. Although efficiencies have greatly increased over the last century, however the energy demand is continuously rising because of the continuous climb in population figures in sync with the demand. It may also be noted that the energy supply chain is heavily reliant on the modes used for the transport of feed stocks as well as the finished products (i.e. energy carriers such as hydrogen and/or fuels).

Renewable sources being widely dispersed require greater dependence on the transportation modes with significant effects on delivery infrastructure in urban and rural regions.

This study is focused on designing a system for renewable production of hydrogen and its delivery through the 3-modes, relevant to the scope of this thesis i.e.:

a. Hydrogen in gas pipeline network.

b. Hydrogen as a liquid in tankers.

c. Hydrogen as compressed gas in containers.

In all these cases, the cost of hydrogen are primarily based on two factors i.e. the cost of the input raw materials and the mode/facility of production. Transport is a major factor contributing to the cost of hydrogen fuel. Problems of establishing production facility are also part of designing the network and associated logistical analysis.

The decision for placement of a plant can be addressed in a variety of ways. The cost of transportation between the production facility and the end user is one of the significant input data to the placement model. In the present work, the process of transporting H2 fuel through various modes is studied along with the placement as the same are closely linked with the consumer centres.

Developing a supply chain model is in-deterministic with respect to the consumer requirements, provision and the technique. Various techniques have been employed to the modeling problem such as [1] [2] [3]. In the current work, deterministic approach has been applied with minor change in the stochastic models.

2. Model Build up

The model builds on the objective of determining the quantity of hydrogen and size of the hydrogen generation facilities in a network that maximizes the efficiency (in terms of the mode of transport and the paths to be adopted) between the feed stock sources and the production facilities as well as the H_2 -path from the generation facility to the end consumer.

Four constituent parts of the model can be identified as:

a. A database containing the sources of biomass availability, its forecasted requirement as well as the distance between the user and consumer.

b. Cost effect of each constituent part of the model.

c. An optimized model based on Mixed Integer Non Linear Programming.

d. Model conception based on the results.

2.1. Assumptions

a. The sources of biomass feed stocks are identified.

b. Energy consumption centres and extent of H_2 fuel requirement is previously known.

c. Likely placement of generation facilities.

d. Input material is transported through wheeled vehicle such as cart, truck or dumper etc.

e. Mode of H_2 delivery is via pipeline, liquid fuel bowzers and gas trucks.

f. The complete system is assumed at steady state with no increase in otherwise fluctuating demand.

g. Optimization is based on the cost of generating H_2 from agriculture residue.

Table 1.1. Index and Subscript Assignment

Index	Description (refer to Fig 4)
r	Feed stock resource
s	H_2 generation facilities location
t	Energy consumption centres
m	Mode of H_2 transport

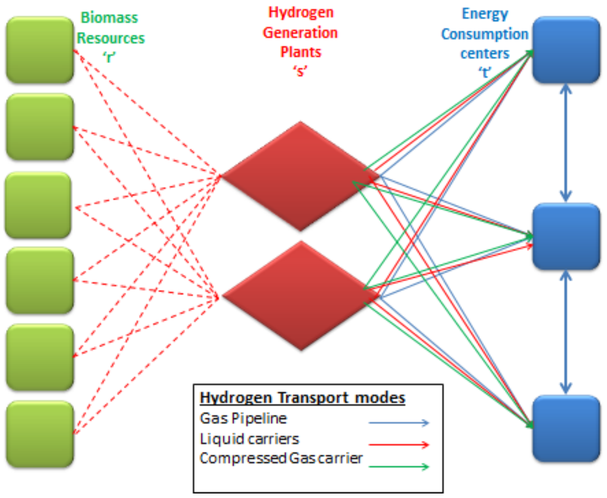

Fig 1. Representative Biomass supply chain

Table 1.2. Data provision to the model

Biomass Resource	Biomass harvested from area 'r' (tons/yr)
P_t	Price of H_2 at energy consumption center 't' ($/kg)
Requirement/day$_t$	Daily requirement at energy consumption centre 't'(kg/day)
α_q	Factor to scale the different technologies
H	H_2 obtained from unit biomass residue (kg/ton)
B_loss^m	Factor to account for the loss of biomass input during delivery and stowage.
t_loss^m	Factor to account for the loss of H_2 from the terminal of mode 'm'
D_loss^m	Factor to account for the loss of H_2 from the distribution system in mode 'm'
d_{rs}	Biomass resource area 'r' & production facility 's' distances in km
d_{st}	Production facility 's' and energy consumption centre 't' distances in kms

2.2. Variables' Definition

Table 1.3

Decision variable	Description
R_{rs}	Annual amount of biomass resource provided from resource 'r' to the production facility 's' (tons/yr).
C_s	Daily production capability of hydrogen in kg from facility 's'.
$T^m{}_s$	Dispensing Capability of mode 'm' from facility 's'.
$H^m{}_{st}$	Capability of transporting hydrogen by mode 'm' from facility 's' to energy consumption centre 't' in kg/day.
Hbv_{st}	Binary variable for availability of pipe-line between production facility 's' and energy consumption center 't'.
I_{t1t2}	Pipe capacity for transporting hydrogen between energy consumption centres t_1 and t_2 in kg of H_2/day.
Ibv_{t1t2}	Binary variable for availability of pipe line between energy consumption centre t_1 and $t_{2.}$
$SC^m{}_t$	Capability of mode 'm' to supply hydrogen to energy consumption centre 't' (kg/day).

Table 1.4. Intermediate variables (cost in $/yr)

RC_{rs}	Biomass resource from area ‘r’ to production facility’s’
PC_s	Production cost at facility ‘s’
TC^m_s	Cost at terminal for facility ‘s’ by delivery mode ‘m’
DC^m_{st}	Cost of transportation from production plant’s’ to energy consumption centre ‘t’ by mode ‘m’
IC_{t1t2}	Transport cost through pipeline between two consumption centres t_1 and t_2
LC^m_t	Transport cost for local distribution within the city through ‘m’ mode
RC^m_t	Cost of refueling at energy consumption centres ‘t’ recieving hydrogen through mode ‘m’
X_t	Annual sale of H_2 in energy consumption centre ‘t’

Objective function is designed to maximize profits and is given by:

Maximize

$$Z=\sum_t P_t X_t\text{-yearly cost} \tag{1.1}$$

$$\text{Yearly cost} = \sum_{rs} RC_{rs}(R_{rs}, d_{rs})+ \sum_s PC_s(C_s) + \sum_{m,s} TC_s^m(T_s^m)+ \sum_{s,t,m} DC_{st}^m(H_{st}^m, d_{st}) + \sum_{t1,t2} IC_{t1,t2}\left(H_{t1,t2}, d_{t1,t2}\right) + \sum_{t,m} LC_t^m(SC_t^m) + \sum_t RC_t^m(SC_t^m) \tag{1.2}$$

Yearly cost of producing hydrogen is dependant on the individual ability of the network components along with the amount of hydrogen feed stocks that are transported and converted to hydrogen at each of the plants and delivered to various energy consumption centres. As already mentioned, the quantities produced at each node and delivered there from is assumed to be constant. CF indicates a proportion of the production capacity that is utilized.

Cost of biomass resource includes the harvesting, storing and stacking per unit weight i.e. tons

RC_{rs} (R_{rs},d_{rs}) = (cost of harvest$_r$ + cost of stowage$_r$ + cost of transport $_{rs}$(d_{rs}).R_{rs}) (1.3)

Production cost:

It includes the cost of installing the production facility as well as the cost of operation and other overheads. CRF stands for capital recovery factor is the amount of interest that may be paid on yearly basis depending on the cost of installation of production facility.

PCs(Cs) = (capital recovery factor+ overheads + maint) x capital cost. $C^\alpha_s+\sum_q variable\ cost\ _q.C_s.CF$ (1.4)

At the site of production another cost added to the H_2 fuel is its preparation for onward delivery which is referred here as the terminal cost (TC_s^m). This cost basically represents the costs of establishing and operating the terminal machinery.

$$TC_s^m(T_s^m) = \sum_q (CRF\ _q{+}overheads + maint).capital\ cost\ \ _q(T_s^m)^{aq} + \sum_q variable\ cost\ _q.T_s{}^m.CF \sum_q variable\ cost\ _q.T_s{}^m.CF \tag{1.5}$$

The cost of delivering H_2 can be broken down into the costs incurred for delivery by pipe line and secondly the costs for transportation by truck mode.

$DC^{m=gas,liquid}(H_{st}^m, d_{st})=(CRF\ _{trl}{+}overheads + maint_{trl}).capital\ cost\ \ _{trl}$

(#trl (H_{st}^m)+op pay(#trl (H_{st}^m)) + per km^m. d_{st} (1.6)

Transporting through network of pipes includes the cost of running the machinery and those involved in maintain it. Compressors used in pipe line networks are included in the cost already calculated for the terminals.

$DC_{st}^{m=pipe}$ = (Hbv_{st},d_{st}) = (CRF+overhead +maint) x capital cost x $Hbv_{st}.d_{st}$ (1.7)

Transportation of hydrogen gas between two energy consumtion centres is also treated with binary variable, Ibv_{t1t2}, it is given by:

IC_{t1t2} (Ib_{t1t2},d_{t1t2}) = (CRF+overhead +maint) x capital cost x $Ib_{t1t2}.d_{t1t2}$ (1.8)

Each delivery mode has some additional charges incurred to replenish the fueling stations

$$RC^m_t(SC^m_t)=\sum_q (CRF\ _q{+}overheads + maint).capital\ cost\ \ _q(SC_t^m)^{aq} + \sum_q variable\ cost\ _q.SC_t{}^m.CF \tag{1.9}$$

2.3. Constraints:

For real life modeling of the scenario, certain constraints need to be applied to the objective function. If there are no limitations in the form of constraints, the modeling scenario would aim to generate and sale unlimited amounts of H_2, which would ultimately lead to unlimited profits.

Constraint on yield

The crop harvested for input to any production facility ‘s’ from any agricultural field ‘r’ has to be within the harvest yield.

$$\sum_s R_{rs} \leq \text{Biomass resource}_r \tag{1.10}$$

The annual production capability of any facility has to be more than the biomass resource being made available to the production plant. B_loss make up for the loss of feed stock in transport and stowage.

$$\sum_s B\_loss.R_{rs}.H \leq 365.CF.C_s \tag{1.11}$$

H accounts for the amount of hydrogen that is obtained from a given quantity of Biomass resource.

The terminals at the production facility must be able to handle the generation capacity of the facility

$\sum_m T_s{}^m = C_s$ (1.12)

Similarly the capability of a terminal at 'm' should be larger as compared to output of the hydrogen production capacity at that mode.

$\sum_t H^m{}_{st} \leq$ t_lossm.T^m_s (1.13)

The distribution network of an energy consumption centre must be able to handle the amount of hydrogen coming into the area 't'

$\sum_s d\_loss^{gas,liquid} T_{st}{}^{gas,liquid} \leq S_t{}^{gas,liquid}$ (1.14)

Correspondingly, the gas network within the local energy consumption centre must be able to handle the amount of hydrogen coming in the area 't' through the pipe supplying the area

$$\sum_s d\_loss^{pipe}.H_{st}{}^{pipe} + \sum_{t_2} I_{\ t_2 t} - \sum_{t_2} I_{\ tt_2} \leq \quad SC_t{}^{pipe} \quad (1.15)$$

Distribution network of an energy consumption centre should have a higher capacity than the quantity of H_2 being sold at any energy consumption centre given by

$X_t \leq \sum_m 365.CF.S_t^m$ (1.16)

The sale of H_2 at any energy centre't' cannot be greater than the requirement of H_2 at the same energy consumption centre.

$X_t \leq$ daily demand$_t$.365 (1.17)

Limitations in terms of constraints also apply to the production facility. The quantity of H2 obtainable from a given biomass resource must be the same as that obtained as output in the form of H2 from the production plant. In this regard the presence or else in case of a pipeline is represented by the binary variable.

$$\begin{aligned}\sum_r B_{loss}.R_{rs}.H = &\sum_t H_{st}^{gas} t\_loss^{gas} \\ &+ \sum_t H_{st}^{liquid} t\_loss^{liquid} \\ &+ \sum_t Hbv_{st}.H_{st}^{pipe} t\_loss^{pipe}\end{aligned} \quad (1.18)$$

In the energy consumption centre, the presence of a local pipeline within area 't' is defined by the binary variable 'Ibv_{t1t2}'

$$\begin{aligned}\sum_s d\_loss^{gas}.H_{st}^{gas} + &\sum_s d\_loss^{liquid}.H_{st}^{liquid} \\ &+ \sum_s d\_loss^{gas}.H_{st}^{gas}.Hbv_{st} \\ &+ \sum_{t2} Ibv_{t2t}.I_{t2t} - \sum_{t2} Ibv_{tt2}.I_{tt2} = X_t\end{aligned} \quad (1.19)$$

The capacities of all areas, production facility as well as transport modes are non-zero entities.

$$X_t \geq 0$$

$$R_{rs} \geq 0$$

$$C_s \geq 0$$

$$T_s^m \geq 0$$

$$H_{st}^m \geq 0$$

$$I_{t1t2} \geq 0$$

$$S_t^m \geq 0$$

3. Database

Throughout the course of this work, it was found that statistical base is either non-existent or minimally addressed in most of the government departments (in Pakistan). In order to present a real life model as developed above - accurate data is required for presentable results and conclusions.

Nevertheless, no worthwhile data on land-use, quantity and type of biomass/crops is available. Similarly no statistics are available for the energy consumption city-wise, district - wise or any other category. Neither the vehicles plying in any area nor the number of fuel (CNG, petrol, diesel) stations in any given region are documented.

Similarly for any model to be developed especially when placement of production facilities is being considered, modeling region has to be carefully mapped. Also, the pipeline network, availability of trucks/trailers and their charges are neither documented, nor can be quoted for any concrete research output.

Moreover energy consumption centers are to be based on urban/rural consumption data, whereby clusters are generated to designate a sizable energy demand center. Identification of energy consumption centres than has to define its center for the purpose of calculating the distances.

Biomass feed-stocks from agriculture residue are an important statistical figure in the choice of potential placement of hydrogen production facilities. This is essential not only to minimize the transportation costs of biomass feed stocks but also the terminal costs, thereby minimizing the overall cost and optimization of the entire Renewable Hydrogen supply chain.

Thus the complete exercise remained academic in the absence of real life data. Instead data available from the internet for statistically advanced countries was used to present the viability of an otherwise practical model. For the purpose of this study the energy requirement was calculated on the basis of per capita energy requirement @ 48.4 KW [4].

4. Cost for elements of Hydrogen supply chain

All the components of this biomass based renewable hydrogen chain i.e. biomass feed stocks, transportation, stowage, cost of conversion, the delivery network, the dispenser facilities have to have a price-based function. In the complete absence of relevant data, cost data had to be derived from external sources. During the course of literature survey, following reports were analyzed for use of relevant data:

a. Gasification-based fuels and electricity production from biomass by Eric. D. Larson [5].

b. H2A Delivery components, published by the United States Department of Energy, for costs pertaining to the delivery of H2 to energy consumption centres [6].

Cost of biomass residue has been reported in various biomass studies with different connotations. For the purpose of this study these costs have been replicated from a study by Jenkins et al [7] titled, "Equipment Performance, Costs, and Constraints in the Commercial Harvesting of Rice Straw for Industrial Applications". The study takes into account various methods for harvesting and includes all fuel costs involved in this process. Summary is given in table below:

Table 1.5

Methods	Basic Cost ($/wet ton)	Fuel charges ($/wet ton)
Rake method	1.40	0.85
Swath method	5.16	2.71
Bale formation	4.96	1.43
Roadside Transfer	3.68+1.05*r	0.75+0.30*r
Total	11.45+1.05*r	3.73+0.30*r

*r denotes the radius of the agriculture resource area

The model can be evaluated with a no of problems as regards the availability of biomass feed-stocks and the level of hydrogen demand. This results in a matrix of case studies that can be evaluated for conclusions, as shown in Table.

Table 1.6

Hydrogen Demand	Biomass feed-stock availability							
		5%	10%	25%	30%	40%	50%	75%
	1%							
	10%							
	25%							
	50%							

28 different case studies have been exhibited in Table 1.6 and the same can be enhanced for detailed evaluation.

For the purpose of evaluation the energy demand was selected corresponding to that of Faisalabad. The city was selected owing to the extraordinary agricultural output and consequent anticipated biomass availability in the area and its surroundings. Faisalabad's major crops include maize, rice, sugarcane, millet, wheat, barley, gram and fodder. Moreover improved varieties of seeds, fertilizers and pesticides have greatly increased per-acre yield. Annual demand of hydrogen is set at 4031072 kg/day, equivalent to 4.031 kilo tonnes that have been generated keeping in view the energy consumption per capita and population of the area. However since a lot of data is based on assumptions, hence only results for 10% demand of Hydrogen are presented here to demonstrate the applicability of this model. Results are presented in Table 1.7 to Table 1.9.

Table. 1.7. Production Plant and allied costs

Hydrogen demand Biomass feed aval	10% 75%	10% 50%	10% 25%	10% 5%
Hydrogen Production Facility				
Production rate(kg/day) Initial Investment $ Cost of Feed-stock/annum Overhead & maint costs/yr	291,979 398,809,300 62,758,688 23,289,902	193,602 286,318,511 43,897,224 16,179,316	93,000 177,517,800 20,826,513 9,852,692	19,843 56,439,176 4,541,621 3,112,960

Table 1.8 provides the costs incurred at the terminal for various modes of Hydrogen transportation i.e. pipeline, liquid H2 carriers and compressed gas trucks. It is evident from the figures that pipeline costs have not been indicated because of the low demand volume and consequent low production. Similarly costs for liquefied hydrogen terminal have also not been shown for feed-stock availability of less than 75%.

Table 1.8

Costs incurred at Terminal of various categories				
Hydrogen demand Biomass feed aval	10% 75%	10% 50%	10% 25%	10% 5%
Compressed H_2				
Volume handled(kg/day) Initial investment($) Overhead & maint /annum		235,756 119,341,511 14,420,761	120,681 73,479,894 8,827,365	25,195 23,501,858 2,829,901
Liquefied H_2				
Volume handled(kg/day) Initial investment($) Overhead & maint /annum	362,369 428,860,311 17,225,470			
H_2 pipeline				

Volume handled(kg/day) Initial investment($) Overhead & maint /annum				

The following table indicates the costs for distribution of hydrogen in the energy consumption centres via the Gas/Liquid Hydrogen carriers and through the hydrogen pipeline. Corresponding to Table 1.8, this table also indicates a proposition for distribution of hydrogen through compressed hydrogen carriers at lower availability of feed stock. At 75% availability liquid trucks are employed while pipe-line may be non-existent owing to the lack of hydrogen demand.

Table 1.9

Costs incurred in various Distribution modes				
Hydrogen demand Biomass feed aval	10% 75%	10% 50%	10% 25%	10% 5%
Compressed H_2 carriers				
No of carriers Initial investment($) Overhead & maint /annum		171 162,787,511 41,073,486	93 82,516,956 19,233,177	25 16,722,509 3,892,132
Liquefied H_2 carriers				
No of carriers Initial investment($) Overhead & maint /annum	31 16,838,786 8,653,695			
H_2 pipeline				
Length in kms Initial investment($) Overhead & maint /annum				

5. Discussion

Other costs assumed for this study derived from literature survey are given at Appendix A. The model has been developed for optimizing the production of hydrogen from Biomass resources. The unit cost of hydrogen for 10% demand comes to $3.95-5.14/kg. This is comparable to the hydrogen costs presently achievable from steam methane reforming process of natural gas. [8] has documented delivered cost of hydrogen from SMR ranging from $ 4.5-5/kg of hydrogen. Cost comparison of various hydrogen generation technologies is given in Fig 6.4. However the full extent of its benefits can be assessed when it is fully integrated with an accurate Database of Biomass feed stocks and a Geographical Information System. Moreover as already highlighted statistics form a backbone of any model whose conclusions are based on data. A model is only as realistic as the statistical base provided to it. This model provides a detailed insight into the hydrogen supply chain based on biomass and assesses the cost incurred in production, transportation and distribution of hydrogen in the energy consumption centers.

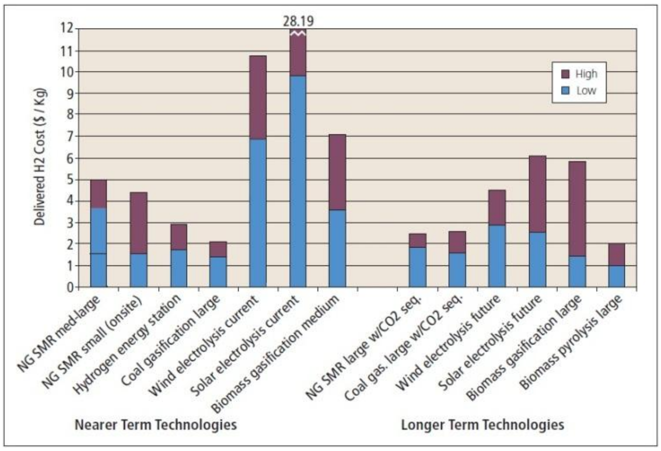

Fig 2. Comparison of delivered hydrogen estimates

The model is an important decision making tool if hydrogen economy is to be realized through renewable energy resources. The costs incurred in biomass-based hydrogen chain can be brought in comparison with other resources for furthering the analysis of the energy infrastructure.

Energy Infrastructure has several components/elements that are linked together in optimization to deliver economically suitable fuel to the consumers. The most important components of an energy infrastructure are:

1. Production/Generation
2. Transportation

The scope of this study has been the generation of hydrogen through renewable resources that have been assessed from Wind, solar and biomass in the preceding chapters. The transportation of hydrogen through the following modes:

a. Compressed H_2 trucks.

b. Liquefied H_2 trailers.

c. Dedicated H_2 pipelines.

have been evaluated in various studies. Fig 3 indicates the hydrogen flow corresponding to various distances in kilometers. The table is a guideline for transportation of hydrogen as a gas and liquid. Since dedicated hydrogen pipelines are neither available nor the same can be built in the near future, hence the initiation of hydrogen economy would entail transport of hydrogen as liquid or gaseous form.

Hydrogen Flow [kg/day]	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500
2000	G	G	G	G	G	G	G	G	G	G	G	G	G	L	L	L	L	L	L	L
4000	G	G	G	G	G	G	G	G	G	G	L	L	L	L	L	L	L	L	L	L
6000	G	G	G	G	G	G	G	G	L	L	L	L	L	L	L	L	L	L	L	L
8000	P	G	G	G	G	G	G	G	L	L	L	L	L	L	L	L	L	L	L	L
10000	P	G	G	G	G	G	G	L	L	L	L	L	L	L	L	L	L	L	L	L
12000	P	G	G	G	G	G	L	L	L	L	L	L	L	L	L	L	L	L	L	L
14000	P	P	P	G	G	G	L	L	L	L	L	L	L	L	L	L	L	L	L	L
16000	P	P	P	P	P	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
18000	P	P	P	P	P	P	L	L	L	L	L	L	L	L	L	L	L	L	L	L
20000	P	P	P	P	P	P	L	L	L	L	L	L	L	L	L	L	L	L	L	L
30000	P	P	P	P	P	P	P	P	P	L	L	L	L	L	L	L	L	L	L	L
40000	P	P	P	P	P	P	P	P	P	P	P	L	L	L	L	L	L	L	L	L
50000	P	P	P	P	P	P	P	P	P	P	P	P	P	P	L	L	L	L	L	L
60000	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	L	L	L	L
70000	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	L
80000	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
90000	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
100000	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P

Fig 3. Hydrogen delivery options Vs Hydrogen flow and distances [9]

The analysis of the various renewable resources available in Pakistan discussed in previous sections leads to an Integrated Renewable Hydrogen model. This model is heavily reliant on three Renewable resources i.e. solar, wind and biomass. While solar and wind energy are essential for the generation of electricity which is used to run the electrolyser. Electrolyser generates hydrogen and oxygen from the electrolysis of water. The hydrogen then generated has to be transported to the energy consumption centers. It has been demonstrated that hydrogen can only be transported in the distribution network upto 17% by volume, without any major changes in pipeline material and network. However for any larger amount of hydrogen, other techniques that can be used are by converting hydrogen into methane and injecting the same into the existing transmission/distribution networks. Another method is to convert hydrogen into methanol and then transport it through liquid fuel tankers to the energy consumption centres.

5.1. Geographical Information System

GIS forms one of the most significant elements of any developing energy supply chain model. In this model the pipeline network of the natural gas distribution companies has to be interfaced with a GIS system. Moreover, a data base of biomass feed stock availability is also to be integrated to arrive at a decision as to the actual potential of hydrogen from any area. Schematic diagram of the GIS assisted and Biomass based renewable hydrogen model is given in Fig 4. GIS has to identify following important information for this system:

1) Biomass Resource

a) Area of agricultural fields with geographical coordinates.

b) Type of crops.

c) Topographical information.

d) Output from the fields as per the coordinates in terms of longitude/latitude.

2) Infrastructural information

a) Road networks - distance from fields to nearest road head.

b) Pipeline networks - gas transmission and distribution networks.

3) Geographical data

a) Terrain

b) Wind data

c) Solar data

d) Urban/rural categorization.

e) Land use - forest/river/sea/protected areas.

4) Energy requirement

a) Indigenous sources of energy

b) Population density

c) Cost of fuel

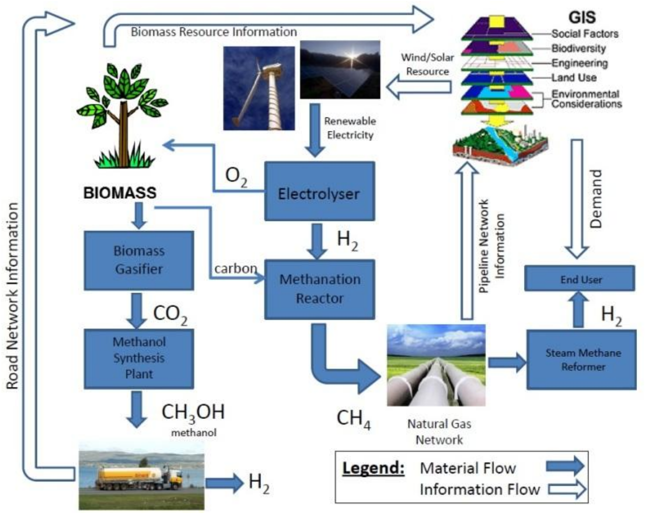

Fig 4. GIS assisted Biomass based Renewable Hydrogen System

6. Conclusion

A Mixed Integer Non Linear Program has been used to develop a tool for analyzing a hydrogen supply chain on biomass feed stocks. It has been concluded that hydrogen production from biomass feed stocks can economically produce hydrogen at competitive rates. Two significant components identified for a strong foundation of the model are, the Database and a realistic Geographical Information

System (GIS). Both the elements are essentially required for accurate results basing on which energy planners can take concrete steps.

References

[1] Snyder, L.V, Facility location under certainty: A review. IIE Transactions, 38, 7, 547-564.

[2] Jia, H., Ordonez, F., Maged, D., A modeling framework for facility location of medical services for large scale emergencies.

[3] Beraldi, P., Brubi, M.E., Conforti, D., Designing robust emergency medical service via stochastic programming. European Journal of Operational Research, 158, 1, 183-193.

[4] Pakistan Energy Year Book, Hydrocarbon Development Institute of Pakistan, 2009.

[5] Larson, E., Jin. H., Williams,R.H., Gasification based fuels and electricity production from biomass, without and with carbon capture and storage, Princeton Environmental Institute, Princeton University.

[6] H2A Delivery components accessed vide http://www.hydrogen.energy.gov/pdfs/h2a_delivery_doc.pdf dated 12 Feb 2011.

[7] Jenkins, B.M., Bakker-Dhaliwal, R., Equipment performances, costs, and constraints in the commercial harvesting of rice straw for industrial applications", ASAE Annual International Meeting, 2000.

[8] Timothy E. Lipman, Jennifer L. Edwards, Cameron Brooks Renewable Hydrogen: Technology Review and Policy Recommendations for State-Level Sustainable Energy Futures, Institute of Transportation studies, University of California, May 2006.

[9] Yang, C. and J. Ogden, (2007), Determining the lowest-cost hydrogen delivery mode, International Journal of Hydrogen Energy, no. 32, pp. 268-286.