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Assessment of hydrogen fuel supply options in India

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Executive summary

The study was carried out by TERI, Delhi for BHEL, Hyderabad for preparation of a project document on fuel cell bus development in India under the UNDP-GEF program. The study assessed the availability and costs of hydrogen production from sources as mentioned in the scope of the project. As part of the study suitable fuel supply options for cities of Delhi and Hyderabad and requirements of refueling station were suggested. The findings of the reports were based on the data and information available at the time of writing the report.

- The availability and costs of production of hydrogen and hydrogen carriers from various sources were assessed;

Source	Quantum	Costs of production
Direct Production		
Chlor-alkali Plants	85.37 Million Nm^3/year	Rs3.50-20.00/ Nm^3
Petro-chemical Plants	237.60 Million Nm^3/year	–
Refineries	As per the requirement	–
Electrolysis	288-7639 Million Nm^3/year	Rs 2.43-6.65/Nm^3
Thermo-chemical Conversion		
Natural Gas	2.77-2.61 Nm^3/NG	Rs 3.67/Nm^3
Coal	1265 Billion Nm^3/year	Rs. 4.70/ Nm^3
Biomass	1015 Million Nm^3/year	Rs 5.99/ Nm^3
Municipal solid waste	3318-7096 Million Nm^3/year	Rs 5.53/ Nm^3
Hydrogen carriers		
Methanol from natural gas	1.5-1.47 lts/Nm^3 of NG	Rs 6.96/litre
Methanol from coal gas	0.85 tonne/tonne of coal	Rs 7.23/litre
Methanol from biomass & waste	52 Million litres/year	Rs 8.04/litre
Ethanol	576.5 Million litres/year	Rs 19/litre

- Fuel demand for a fleet demonstration of 10 buses (as per Ballard's Phase-II PEMFC bus specifications) has been assessed at 1692 Nm^3/ day.
- The refueling station capacity is estimated at 2000 Nm^3/ day. Refueling of 5 buses will be done per day and the fuel will last for two days trips comprising of a total of 396 km.
- The suggested fuel supply option will be from direct hydrogen from a chlor-alkali plant with a delivered hydrogen cost range of Rs. 10.88 –27.38 / Nm^3.
- The refueling station can be sited at depots of local Transport Corporation of the city where the demonstration project will be carried out. Fuel cell buses will be stationed at this depot after completing the day's trips.

1 Direct hydrogen from industrial sites

Hydrogen is produced as a by-product in various industrial processes. The major industries where hydrogen is produced as a by-product are ;

- Chlor-alkali Industry
- Petroleum Refinery
- Petro-chemical Industry

The by-product hydrogen produced in these industries varies in quality and quantity depending upon the type and size of the industry. Some of the industries have excess hydrogen available whereas some others are using hydrogen as fuel or as a feed in chemical processes. In order to assess a detailed position of hydrogen availability a questionnaire along with brief write up on fuel cell and fuel cell vehicles was mailed to all the group of industrial plants as mentioned above. The questionnaire was aimed at getting following information from the manufacturer

- Hydrogen Production
- Hydrogen Consumption
- Market demand
- Selling cost
- Expansion plan

The responses and other details are presented in following section.

Chlor-alkali industry

The chlor-alkali industry in India mainly comprises of manufacturers of caustic soda(NaOH) and soda ash (Na_2CO_3). Caustic soda or Sodium hydroxide is manufactured from electrolysis of brine solution. Major by-products in NaOH manufacturing process are chlorine and hydrogen, as shown by the basic chemical reaction;

$$NaCl_{aq} + H_2O \Rightarrow NaOH + \frac{1}{2}H_2(g) + \frac{1}{2}Cl_2$$

The total installed capacity and the production of caustic soda in India, in last 3 years is listed in Table1.1. Caustic soda and chlorine are used in diverse industrial sectors, either as raw materials or as auxiliary chemicals. Caustic soda is mainly used in the manufacture of pulp and paper, newsprint, viscose yarn, staple fibre, aluminium, cotton, textiles, toilet and laundry soaps, detergents, dyestuffs, drugs and pharmaceuticals, vanaspati, petroleum refining etc. Whereas chlorine is used for manufacture of PVC, pulp and paper, bleaching powder and a host of other inorganic and organic chlorinated compounds.

Table 1.1 Installed capacity(,000 TPA), and annual production of caustic soda in India

Year	Installed Capacity	Annual Production	Capacity utilization(%)
1995-96	1673.0	1308.7	78.2
1996-97	1914.0	1320.0	69.0
1997-98	2028.5	1419.5	70.0
1998-99	2266.7	–	–

Source. AMAI, Annual Report (various issues), New Delhi: Alkali Manufacturers Association of India

Hydrogen produced from chlor-alkali industry is mainly used for the manufacture of hydro-chloric acid and as a fuel. There are other limited uses like hydrogenation of oils, manufacture of hydrogen peroxide etc.

Hydrogen availability from chlor-alkali Industries

There are 39 chlor-alkali manufacture as listed in the directory of chlor-alkali manufacturers association published in the year 1998. These plants have installed capacities of 10000 –200000 tonnes per annum. The consumption pattern of by-product hydrogen varies from plant to plant. Some of manufacturers use hydrogen, along with chlorine, for making hydrochloric acid. Another portion is compressed and sold as a product, however a major portion is either burnt as a fuel in the caustic concentration step or simply vented to the atmosphere, for want of better means of utilization.

The hydrogen availability was assessed from the responses to the questionnaires sent to all the manufacturers in India. It was assumed that the present in-house use and selling of hydrogen will continue in near future, therefore excess hydrogen which is being vented was taken as the contribution towards the availability. A sizeable portion of by-product hydrogen in chlor-alkali plants is used as fuel for concentrating caustic soda lyes, This portion can also be made available in medium term future if cheap alternative fuel is provided to these industries for the concentration step. However , since the use of hydrogen as fuel for concentration step is going to continue in near future, therefore share of hydrogen under this was not counted under the availability head. The total installed capacity and by-product hydrogen produced and the excess available from various chlor-alkali plants is listed in Table 1.2. The data is based on the information provided by the manufacturers in response to our questionnaires. The questionnaires were sent to about 39 manufacturers, totaling an installed capacity of 2266.72 thousand TPA. However the responses were received from only 19 manufacturers of which 7 manufacturers have no excess available. The non-availability in 2 of these 7 plants was due to extensive in-house consumption whereas the remaining had very small installed capacity hence per day release of hydrogen itself was quite small.

From Table1.2 , the excess hydrogen availability is 133994 Nm^3/ day from an installed capacities of 775.82 thousands TPA. The excess available is about 21.25% of the total hydrogen produced as by-product. The selling price of hydrogen varies from Rs.3.50–20 per Nm^3.

The hydrogen availability from the remaining manufacturers from which the responses were not received at the time of writing the report was calculated by assuming the installed capacity of 1000 thousand TPA, a capacity utilization factor of 70% and the excess hydrogen availability of 21% of the total produced.

Table 1.2 Installed capacities, hydrogen produced per day, and excess hydrogen available from various chlor alkali plants in India.

Manufacturers name & State	Installed Cap. (TPA)	H_2 Produced (Nm^3/Day)	Excess H_2 (Nm^3/Day)	Selling Price of H_2 (Rs. /Nm^3)
Century Rayon, Maharashtra	33000	11000	11000	15
Hukumchand Jute Inds. Ltd,Madhya Pradesh	47520	23100	11100	15
Indian Rayon & Inds Ltd., Gujarat	33000	29400	1147	12-15
The Andhra Sugars Limited, Andhra Pradesh	33000	28000	4000	18-20
DCW Limited, Tamilnadu	60000	48160	16800	No assigned cost
Sree Rayalaseema Alkalies & Allied Chemicals Ltd, Andhrapradesh	69300	68800	0	12-13
Hindustan Organic Chemicals Ltd, Maharashtra	20000	15692	0	–
NRC Limited, Maharashtra	33000	28089	842	12
Indian Petrochemicals Corpn Ltd, Gujarat	130000	120000	50000	Driven by market
Bihar Cuastic & Chemical Ltd, Bihar	33000	32704	6519	3.50
Grasim Industries Ltd, Madhya Pradesh	152000	112000	16000	10
Tata Chemicals Ltd, Gujarat	33000	29500	4720	No assigned cost.
Punjab Alkalies & Chemical Ltd	99000	84000	11866	No assigned cost
Total	775820	630445	133994	

The hydrogen available per day from the remaining plants has been assessed at 124728 Nm^3/day. The annual availability assuming a 330 days in years has been calculated in Table 1.3

Table 1.3 Excess hydrogen availability from chlor-alkali plants in India.

Total availability	258722 Nm^3/ day
Total annual availability	85.37 Million Nm^3

Petroleum refineries

The hydrogen generation process in a petroleum refinery may be depicted by the following flow diagram in figure 1.

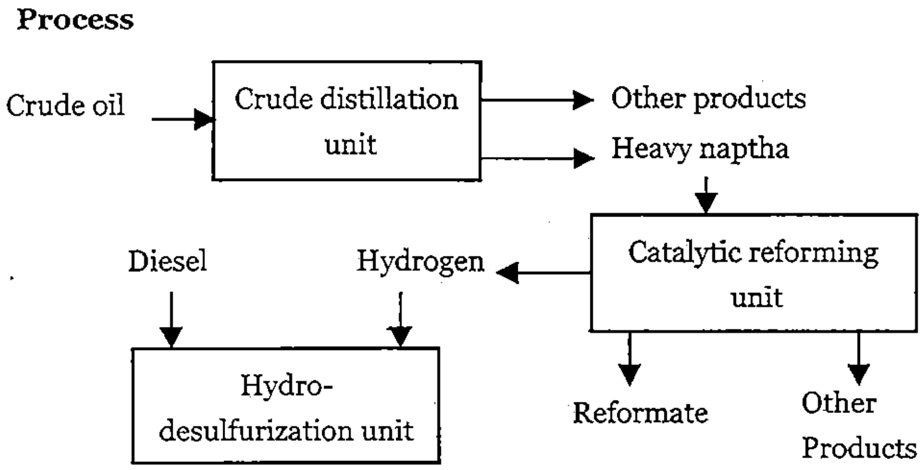

Figure 1.1 The hydrogen generation process in a petroleum industry

Almost all refineries use hydrogen in hydro-treating processes to remove sulphur and nitrogen from product streams and occasionally to saturate aromatics and olefins. Many refineries also consume hydrogen in hydro-cracking and isomerisation. Several current trends in the refining industry are reducing the availability of hydrogen. Low sulphur diesel requires increased hydrogen consumption for hydro-treatment and at the same time reduce the amount of hydrogen produced by catalytic reforming.

DHDS projects

In order to reduce the sulphur content in diesel to 0.25% wt. maximum, and to supply diesel with not more than 0.25% sulphur content throughout the country as per the commitment made to Hon'ble Supreme Court by setting up DHDS units in 9 Refineries has been approved by the Government of India on 4.6.97 at a total cost of Rs.5568 crores. Out of nine, more than five DHDS units are already under operation.

Crude oil processing being more tilted to diesel base combined with requirement of ultra low sulphur level is leading to increased demands of hydrogen in the refineries for use in hydro-desulphurization. Most of the refineries have planned for additional hydrogen generation facilities based on steam reforming of natural gas. Mangalore Refineries & Petro-chemicals Limited is one such example.

Response from Bharat Petroleum Corporation Limited and Reliance Petroleum has already been received, and according to them there is no surplus hydrogen available at their refineries. The same trend is expected for other refineries under Indian Oil Corporation and other oil companies.

In the present scenario the possibility of getting hydrogen from refineries seems to be remote.

Hydrogen from refineries for operating fuel cell buses in Delhi

The Indian Oil Corporation Limited (IOCL) owns seven refineries, however there are only two that are located closest to Delhi. The one located at Mathura in the state of Uttar Pradesh is about 140 km from Delhi whereas the second one at Panipat, in the state of Harayana is about 100 km from Delhi.

For collecting more information on this we met Mr U K Basu, Deputy General Manager (Technical) Refineries Division of Indian Oil Corporation Limited, Delhi. According to Mr Basu, the hydrogen produced during cracking is extensively used for hydro treatment of fuels such as diesel and petrol. The above-mentioned refineries at Panipat and Mathura also have additional hydrogen production capacity based on naphtha as feed stock.

Though the present hydrogen production at these refineries is purposely for in-house consumption however, it is possible for these refineries to gear up to meet the requirement of commercial fleets of fuel cell buses in Delhi. This however will need revamping of the existing generation units, which can be done in 1.5 – 2 years. However before taking any decision they would be interested in knowing the market demand for fuel cell based transportation system.

These refineries are planning to supply diesel and petrol as per the EURO–III requirements in coming few years and accordingly the hydrogen production capacities are expected to go up. However based on the hydrogen production capacities of the Mathura and Panipat Refineries, the requirement of hydrogen for commercial fleet of fuel cell buses for Delhi[#] will be 6.5 % of the annual generation capacities. The future hydrogen consumption in the refineries is expected to go up but additional hydrogen production plants are

[#] As calculated by the international consultant being installed and in that scenario the share for commercial bus fleets may go down to about 4% of the annual production capacity.

Table 1.4 Crude oil processing and hydrogen generation capacities of Mathura and Panipat refinery

Refinery	Processing capacity (MMTPA)	Hydrogen production capacity (TPA)
Mathura	7.5	34000
Panipat	6.0	38000
Total	13.5	72000

Also for meeting the demands of fuel cell bus transportation in Delhi the two refineries will need following modifications

- Dispatch facilities for hydrogen fuel.
- Augmentation of storage facilities such as high pressure tubes.
- Revamping of the units based on the hydrogen requirement for the fuel cell buses.

The time frame required for this revamping can fall into 1.5–2.5 years.

Petro-chemical Industry

The petro-chemical industry in India uses ethylene as a building block for manufacture of polymers like poly-ethylene. This is extensively used in manufacturing different types of plastics. Ethylene is produced by dehydrogenation of ethane, and thus is associated with release of hydrogen. The major petrochemical production based on gas cracking are listed in Table 1.5

Table 1.5 The major gas cracking based petrochemical plants in India

Project	Capacity (tpa)	Status
IPCL, Gandhar, Gujarat	300,000	Operational
IPCL, Nagothane, Maharashtra	400,000	Operational
GAIL, Auraiya, UP	300,000	Operational
RAPL, Tengakht, Assam	300,000	Under Implementation

The hydrogen from Gandhar gas cracker is 60.6 mol%. Out of this, about 15% is used internally after purification through pressure swing adsorption and rest is used as a mixture with other gaseous fuels. Since there is no other gaseous fuel available and gas cracker heaters are designed for gaseous fuel, this hydrogen though very high in volume can not be spared. The details of hydrogen available from Gandhar gas cracker are given in Table1.6.

The Nagothane plant of IPCL have similar composition but available excess flow would be approximately 14000 kg/hr at 100% capacity operation. Though this excess hydrogen is used as gaseous fuel but according to a rough estimate 40,000 Nm^3/ hour is available as excess hydrogen. Assuming plant operation for 18 hours a day, 330 days of the year the annual hydrogen availability has been estimated at 237.6 million Nm^3.

Table 1.6 Details of hydrogen available from Gandhar petrochemical plant

Composition	Mol%
Hydrogen	60.6
Methane	38.5
Ethane	0.1
Carbon monoxide	0.8
Flow	18740 Kg/hr

2 Hydrogen from hydro-electricity

Hydrogen can also be produced by electrolysis of water. The decomposition of water by electrolysis consists of two partial reactions that take place at the two electrodes. The electrodes themselves are separated by an ion-conducting electrolyte. Hydrogen is produced at the negative electrode (cathode) and oxygen at the positive electrode (anode). The necessary exchange of the charge occurs through the flow of ions. In order to keep the produced gases isolated, the two reaction areas are separated by an ion conduction separator (diaphragm). The energy for water electrolysis is supplied in the form of electricity.

Water electrolysis in its conventional form, alkaline electrolysis, has been in commercial use for over 80 years. Up until the end of the eighties, only a vanishingly small portion of approximately 0.5 –1 Billion Nm^3/annum that is 0.1–0.2% of the world production of hydrogen, was directly produced by electrolysis, mainly in connection with hydropower. Even this small quantity is declining since the electrolytic production of hydrogen for fertilizer manufacture is no longer competitive with production from natural gas due to falling energy prices. Because electrolytically produced hydrogen is created indirectly via the energy carrier 'electricity', this process is only economically feasible in places where electricity can be extremely cheaply generated. This is generally only possible with large-scale hydro systems (Egypt, Brazil, Iceland, Canada, Norway, Zaire), or with excess energy from the primary and secondary control of existing power station capacity with significant nuclear component (France, Belgium, Switzerland, some German Electric Utilities).

The following section is intended to describe the electrolysis processes specifically optimized for hydrogen production. These processes are the well tested low pressure electrolysis method and two processes still in the development phase, namely the high pressure and the high temperature processes.

Present state of the art of electrolysis technology

Conventional Water Electrolysis

Process description

Conventional alkaline electrolysis works with an aqueous alkaline electrolyte. The cathode and anode areas are separated by a micro-porous diaphragm to prevent mixing of the product gasses. Presently in Germany, conventional unpressurised electrolysis utilizes new materials that replace the previously used asbestos diaphragm. With output pressures of 0.2–0.5 MPa these processes can reach efficiencies, related to the lower heating value of hydrogen, of around 65%. Newly developed diaphragms and membranes from other materials demonstrate, through their good turn off characteristics, relatively good reliability when subject to fluctuating operating conditions. They are therefore applicable in conjunction with renewable energy technologies.

Who offers electrolysers?

Conventional water electrolysers have been in use commercially for many decades. Units with capacities from 1 kW_{el} to 125 MW_{el} are available. The Electrolyser Corporation Ltd. (Canada), Stuart Energy Inc. (USA) and Norsk Hydro Electrolysers AS (Norway) are well established manufacturers of conventional elctrolysers, offering units with very high capacity. Several manufacturers have also established themselves in the 1–100 kW range in Europe (e.g. Ammonia Casale, ELWATEC, Hidroenergia VCST (up to 1 MPa), vHS (von-Hoerner-System; up to 3 MPa but also unpressurised).

What is the cost of such electrolysers?

Large commercial electrolysers cost between Rs. 10,750–21,000# /kW_{el} but smaller plants are considerably more expensive. The smallest 1 kW_{el} electrolysers can cost up to Rs 2,10,000 with the price only falling to the Rs. 10,750 /kW_{el} figure in the MW range. Operating efficiencies lie in the 50–60% range for the smaller electrolysers and around 65–70% for the larger plants.

What is presently under development?

High pressure water electrolysis

Process description

Through special material choice and optimization, high pressure water electrolysis allows the generation of hydrogen at pressures up to 5 MPa. The

At DM conversion rates of INR 21.5

processes under development attempt to find an appropriate capacity optimization that will also allow for a problem free connection of the electrolyser with a fluctuating current supply (e.g. Wind or PV connection for isolated plants)

Who offers high pressure electrolysers ?

The most important development work to mention is that being carried out by GHW (Gesellschaft für Hochleistungswasserelektrolyseure) for the commercialization of a high performance electrolyser with output pressures up to the 5 MPa level. The goal of these efforts is to reach, along with the high output pressure, an appropriately optimized operating efficiency applicable for strongly varying load. Final commercialization is expected within the next 2–3 years. In the field of small capacity units (under 100 kW), vHS has the appropriate equipment to offer.

What do such electrolysers cost?

The small units from vHS are already available for prices of approximately Rs 2,10,000 /kW. It is expected that the optimised high capacity electrolysers from GWH will be offered at prices around the Rs. 43,000 –53,750/kW mark. However, no binding statements have been made up to now.

High temperature water electrolysis

Process description

High temperature electrolysers were under discussion as an interesting alternative several years ago. The main advantage of such a process would be to obtain part of the energy required for water separation in the form of high temperature heat and thus complete the electrolysis with a lower electricity consumption. The discussions focussed on the use of heat from solar concentrators or waste heat from power stations for this purpose. Corresponding investigations were carried out by DLR in Stuttgart. Interest in this method of electrolysis has however declined in the last few years.

Hydro-electric power generation in India

Falling or flowing water formed the earliest of natural sources of energy. Conditions favoring such developments in India included the availability of sites, the higher efficiencies in power generation promised by hydro-electric sources, compared with fossil fuels and steam plants, and the advent of the technology for high voltage long distance transmission. Hydro-power stations have inherent ability for instantaneous starting and stopping, almost instantaneous load acceptance and rejection. They are ideal for peak load demand and they enhance the system reliability. The fuel cost being zero, cost of the hydro-power generation declines over time unlike the thermal power and in the long run it turns out to be cheaper.

Hydro-electric power is an important source of energy in India. It is a renewable economic, non-polluting and environment friendly source of energy. It enables conservation of limited reserve of non-renewable fossil fuel. Hydro-electric power costs only about Rs 1.10 per unit to produce as against a cost of Rs. 3 to Rs. 4 per unit for thermal plants. Consequently it envisage lower tariffs and moreover these projects are free of any dangerous or hazardous emissions or discharges into the environment.

The economically exploitable hydro-potential of our country has been assessed to yield an annual energy benefit of 600 billion units(including seasonal energy) and estimated installed peak power capacity of over 1,50,000 MW. However, so far only about 15% of the capacity has been exploited.

Installed hydro-generation capacity in India

The installed capacity in the country as on 31 March 1999 was 93252 MW* and the share of hydropower capacity is 22443 MW. During the 8th plan the target for hydro capacity addition was 9282.15 MW against which only 2427.65 MW has been achieved. The 9th plan has assessed the hydro capacity addition of 9820 MW in a total capacity addition of 40245 MW.

Hydro share

The share of installed capacity in hydropower to total installed capacity, which was 33% at the start of first five year plan in 1951, rose up to 46% by the end of Third-Five Year Plan. Average annual growth rate of installed capacity of hydropower plants during this period was around 14%. Despite hydro-electric projects being recognized as the most economical and preferred source of electricity, the share of hydro in the total installed capacity has experienced a steady decline since 1963.

The maximum hydro share attained so far was 50.62% in 1963 as on March, 1999 the hydel installed capacity of 22443 MW in the total capacity of 93252 MW represents share of 24.06%. The average annual rate of growth in the installed capacity of hydro plants came down to as low as 6% during the period

* Source TERI energy data directory and year book 1999-2000

1973–74 to 1989–90. The trend indicates further decline of hydro share in the 9th plan against the ideal figure of 40%. Even if all the capacity addition envisaged for the 9th plan in hydro is achieved, we will be able to increase hydro share marginally from current level of 24..5% to 25.1% at the end of the 9th plan.

Fall in production of hydro share can mainly be attributed to;

- Long gestation periods
- Difficulties in arriving at uniformity of standards and applicable norms for hydro-electric power projects.
- Funding, environmental consideration, and water disputes which no doubt play a role in thermal projects, but take on much longer dimensions in the approval process and implementation of hydro-electric projects.
- Dis-interest of the investors in promoting hydro-power development owing to uneven spread rivers in various states.
- Non availability of such hydro-power for meeting peak demands as it is often linked to irrigation needs.

Balance between hydro-electric and thermal power plants

Although a balance between hydro-electric power and thermal power is, not easy to achieve, however it would be extremely useful as hydro-electric power unlike thermal power has several advantages, the main one being that hydro-electric power can be stored in a dam and used to meet peak energy demands.

As on 31 January 1999, the hydro thermal ratio is only 25:75 (against 40:60 considered economical). Inspite of the emphasis having been given to hydro potential, the proportion of thermal generating installed capacity in our system has maintained an upward increasing trend. With such a hydro-thermal mix and without adequate peaking power plants, the operation of thermal power plants will not be optimum. This needs the development of hydro-electric schemes in India, which are really suited to providing peaking power to the large integrated systems which depend on thermal and nuclear power plants for the base load. Hydro electric schemes will help in improving the the operational reliability, stability and flexibility of the power system and also optimizing the operational economics and to meet the peak demands.

Table 2.1 shows that hydro-thermal mix in our country is not optimal in Western Region and Eastern Region. With such an unfavorable hydro-thermal mix and without special peaking plant, the operation of thermal plants at high plant load factor will be difficult. Operation of thermal power plant at a very low load factor and frequent variations in load of such thermal plants will not only adversely affect the efficiency of the power system and plant life of these power houses but may also necessitate burning of huge amount of petroleum fuel.

Table 2.1 Hydro thermal mix in India – Regionwise

Region	Installed Capacity (MW)				Ratio to total	
	Hydro	Thermal	Nuclear	Total	Hydro (%)	Others (%)
Northern	7655.1	16863.41	895.00	25413.51	30.12	69.88
Western	3194.38	22741.98	860.00	26796.36	11.93	88.07
Southern	8867.69	12413.02	470.00	21750.71	40.77	59.23
Eastern	1765.22	12622.58	0.00	14387.8	12.26	87.74
North-eastern	600.69	1113.74	0.00	1714.43	35.03	64.97
Total	22083.08	65754.73	2225.00	90062.81	24.52	75.48

Source. Annual Report 1998-99, Ministry of Power, Government of India

Pumped storage schemes

In ordinary hydro-electric power stations, hydraulic turbines and electric generators are the main mechanisms, whereas in pumped storage plants there are also hydraulic pumps and electric motors to drive the pump. The pumped storage schemes (PSSs) essentially have two reservoirs/ ponds generally of approximately equal capacity – one upstream (upper reservoir/ head pool) at high elevation and one down stream (lower reservoir/ tail pool) at lower elevation having relatively great difference in altitude but are as near to one another as possible. The schemes are equipped with reversible units so as to act either as a load during pumping mode or as a generating source during generating mode.

In such plants, at times of maximum river flow or during off-peak periods, water is pumped into a storage reservoir on a neighbouring height, or simply back from a lower pool(tail pool) into the headwater pool; and at times of low river flow or during peak power periods, this water is used to generate electricity. Storage may be for lengthy periods to offset seasonal shortages or for short periods to compensate for the daily peaks.

In pumped storage plant the generation of two kilowatt-hours of electric energy requires about three kilowatt-hours of off-peak energy because of the losses from pumping, power generation and transmission to and from the load centre. Despite the inefficiency in pure energy terms, however, such facilities are of great practical efficiency because they allow the use of otherwise wasted off-peak power.

The PSSs provide peaking emergency power and most efficient means for storing large quantity of energy and enhance the peaking power and help in leveling the peaks and valleys of load curve of a power system and thus making the system to operate efficiently and economically. Thus PSSs improve the plant load factor, efficiency, life, fuel consumption and reduce the severe cycling of base load thermal and nuclear power stations and hence improve their operational performance. In addition, these schemes provide system-spinning reserves at no cost and help in maintaining the system frequency at the prescribed value in case of variation of load.

In India, where power systems are generally characterized short of peaking capacity having increased proportion of the thermal (including nuclear) generating capacity results in an unfavorable hydro-thermal mix. As is evident from the Table2.1 inadequate hydro support in the Western and Eastern Region is affecting the performance of the thermal plants as they provide the peaking power, thus having to back down during non-peaking hours.

The predominant thermal base of the western and eastern region could provide availability of off-peak energy for the operation of pumped storage schemes. The emerging profiles of the generation mix in the western region and eastern region as well as the load cycles in these regions indicates the necessity of hydro-electric pumped storage schemes in near future close to the major load centres to ensure the optimum utilization of thermal/ nuclear power projects.

The Central Electricity Authority undertook an elaborate and comprehensive survey of entire India in 1978 for identifying the pumped storage schemes in India and identified 6 additional sites for major pumped storage schemes with and probable target of aggregate installed capacity of 93,920 MW. The regionwise distribution of potential sites identified for installation of pumped storage schemes in India is given in Table 2.2.

Table 2.2 Regionwise distribution of potential identified for installation of pumped storage schemes in India.

Region	Probable Total Installed Capacity	% of total
Northern Region	13065	13.91
Western Region	38220	40.69
Southern Region	16650	17.72
Eastern Region	9085	9.67
North Eastern Region	16900	17.99
Total	93920	

Major pump storage schemes under operation, execution and cleared by CEA are listed in Table 2.3. Some of the operational schemes are being operated in generation mode because of non-availability of tail pool dam.

Table 2.3 Hydro pumped storage scheme development (YOP 1994)

Pumped storage	Status of schemes	Capacity	Total capacity
Kadana stage I (Gujarat)	Operational	2x60 MW	120 MW
Paithon (Maharashtra)	Operational	1x12 MW	12 MW
Nagarjunasagar(AP)	Operational	7x100 MW	700 MW
Kadampari (TN)	Operational	4x100 MW	400 MW
Panchet Hill (DVC)	Operational	1x40 MW	40 MW
Ujjani (Maharashtra)	Operational	1x12 MW	12 MW
Kadana Stage II (Gujarat)	Under execution	2x60 MW	120 MW
Sardar Saroval (Gujarat)	Under execution	6x200 MW	1200 MW
Bhira (Maharashtra)	Under execution	1x150 MW	150 MW
Ghatgar (Maharashtra)	Under execution	2x125 MW	250 MW
Srisailam (AP)	Under execution	6x150 MW	900 MW
Purulia (West Bengal)	CEA techno-econ.clearance	4x225 MW	900 MW
Bivpuri (Maharashtra)	CEA techno-econ.clearance	1x90 MW	90 MW
Tehri Stage II (UP)	CEA techno-econ.clearance	4x250 MW	1000 MW
TOTAL			5894 MW

Source. Irrigation and Power Journal, Golden Jubilee Issue, CBI P, Volume 51, No.1, January 1994

Guidelines for fixation of tariffs

Government of India vide Gazette Notification dated 30 March 1992 notified the guidelines for determination of tariff for sale by generating companies to the SEBs and to other consumers. The notification of 1992 considered a single part tariff for hydro-generating stations as against as two part tariff for fuel burning stations. This was considered disadvantageous by hydro-generating companies. They found the investments less attractive for HEPs. Therefore inline with their suggestions, the gazette notification was subsequently modified in which two part tariff was introduced for HEPs.

Time of Day (TOD) tariff

The present system of tariff fixation does not make distinction between the cost of the power supplied during the peak period and off-peak period. As discussed earlier, the HE projects are ideally suited to supply peak power. If this duty is performed by coal based plants, the variable cost will be much higher during peak periods as compared to hydro who have negligible variable cost. Therefore shifting of hydro-energy from off-peak period to peak period would increase its economic value. However this would require optimal scheduling of various types of plants connected to the system.

The time of the day tariff has already been introduced. It is envisaged that such a tariff system will ensure that hydro-power potential would be fully put to most economic use. This will also contribute in conserving scarce precious fossil fuel by proper utilization of renewable energy source i.e water.

Power situation in India

Power supply position

The power supply position during the last five years and during the April' 98 – January' 99 is listed in Table 2.4 a and Table 2.4b. It may be seen from the table that the energy shortage has been reducing gradually and during the year 1998-99 it has reduced to 5.5%. The peak shortage during the year 1998-99 (April 98–Jan 99) has been little lower than last year.

The position of preparedness in terms of existing generation capacity, sanctioned and on going projects and CEA cleared projects is listed in Table 2.5. The installed capacity required at the end of 11th plan(2011–12) would be of the order of 2,40,000 MW. This leaves a gap of 85,914 MW of projects. Of these new projects aggregating to 61,717 MW have already been identified. However when these projects are put in programme only 57,557 MW get selected on the basis of economics of generation. In other words additional projects aggregating to 28,357 MW need to be identified. @

The additional capacity selected for the period 1999–2012 works out to about 1,20,232 MW comprising 33980 MW hydro, 75,992 MW thermal and 10,260 MW nuclear.

Table 2.4a Power supply position during the last five years

			Energy (Million Units Net)	
Year	Requirement	Availability	Shortage	
			Total	(%)
1993-94	323252	299494	23758	7.3
1994-95	352260	327281	24979	7.1
1995-96	389721	354045	35676	9.2
1996-97	413490	365900	47590	11.5
1997-98	424505	390330	34175	8.1
1998-99	368046	347900	20146	5.5

Source. Annual Report 1998 - 99, Ministry of Power

@ Power on demand by 2012, Perspective Plan Studies, CEA Report, July 1999.

Table 2.4b Power supply position during the last five years

Year	Peak Demand	Peak Met	Deficit	Shortage(%
1993-94	54875	44830	10045	18.3
1994-95	57530	48066	9464	16.5
1995-96	60981	49836	11145	18.3
1996-97	63853	52376	11477	18.0
1997-98	65435	58042	7393	11.3
1998-99	65956	58636	7320	11.1

Table 2.5 Existing, sanctioned and ongoing generation project in India

Existing as on 3/99	91,411 MW*
Sanctioned and ongoing schemes	24,316 MW
CEA cleared	38,359 MW
Total	1,54,086 MW

* As against existing generation capacity of 93,249 MW as on 3/99, the derated capacity is 91,411 MW.

Source. Power on demand by 2012, perspective plan studies, CEA report, July 1995

With this level of capacity additions the installed capacity at the end of the 11th plan works out to about 2,11,643 MW. This level of capacity addition results into a peaking shortage of about 22,600 MW with respect to the 15TH EPS Demand Forecast of 176647 MW. This is a clear indication of insufficient identified power plants.

Availability of electricity for electrolysis

As shown in the Table2.4a the deficit in availability for the year 1998–99 was about 20146 million units. This is a clear indication of acute shortage of electric power in the country. Hence the availability of electricity in India will be a crucial factor in deciding upon the potential success of electrolysis route of producing hydrogen.

For the purpose of assessing the excess electricity available for the electrolysis following assumptions were taken :

- The deficit in generation against the requirement of electricity will continue with in the country for next 15 years though with a decreasing trend.
- The electricity is made available from the grid during off-peak periods.
- All the off-peak power is used in operating pumped storage schemes.

Basis for the assumptions

In a power plant there are certain period during the day as well as during seasons when the generation is more than the demand, and in case where the generations can not be reduced in proportion to demand, attributely to techno-economic factors as in the case of thermal power plants, the use of excess electricity can be done as;

- Encourage the usage by providing electricity at cheaper rates i.e time of the day tariff is made available.
- By charging of batteries
- By using it in pumped storage schemes

In India the condition of off-peak electricity exists for the total grid in a region. A grid is the transmission network interconnecting all the power generation stations and all the loads in a particular region. The eastern region grid and north eastern grid of India have surplus power for 80%# of the time. (there is also some excess available in western region). According to a rough estimate around 12000 MWh per day of off-peak power is available in the eastern region. The quantum of off-peak power is estimated on the difference between the prevailing high frequency and normal frequency (50 Hz) as guide. There is a relation in surplus power and this difference in a particular region depending on the normal demand of the region. For example, in eastern region every one Hz rise above 50 Hz would mean around 500 MW surplus power. So in a way, hydro frequency represents surplus power in the grid. The power stations of these regions are asked to cut down their generation to normalise the frequency. The exact details on the availability and time duration were not available hence above listed assumptions have to taken Ψ.

Magnitude of hydrogen

The magnitude of hydrogen available from electrolysis is dependent on the availability of electricity and water. Assuming the water is available, the economics of hydrogen production from electrolysis force the use of cheap off-peak electricity as the possible source. As mentioned earlier, assuming the installed capacity of pumped storage capacity as an approximate measure of the power available as off-peak, and assuming an electrolyser efficiency of 70%, the annual hydrogen availability estimated is be 850 –7638 Million Nm^3 (depending duration of the off-peak period).

Personal communication with Mr D.P.Bhargava, Chief Engineer, Natl. Hydro Electric Corp.
Ψ Eastern Region Load Dispatch Centre has been contacted for collecting more information

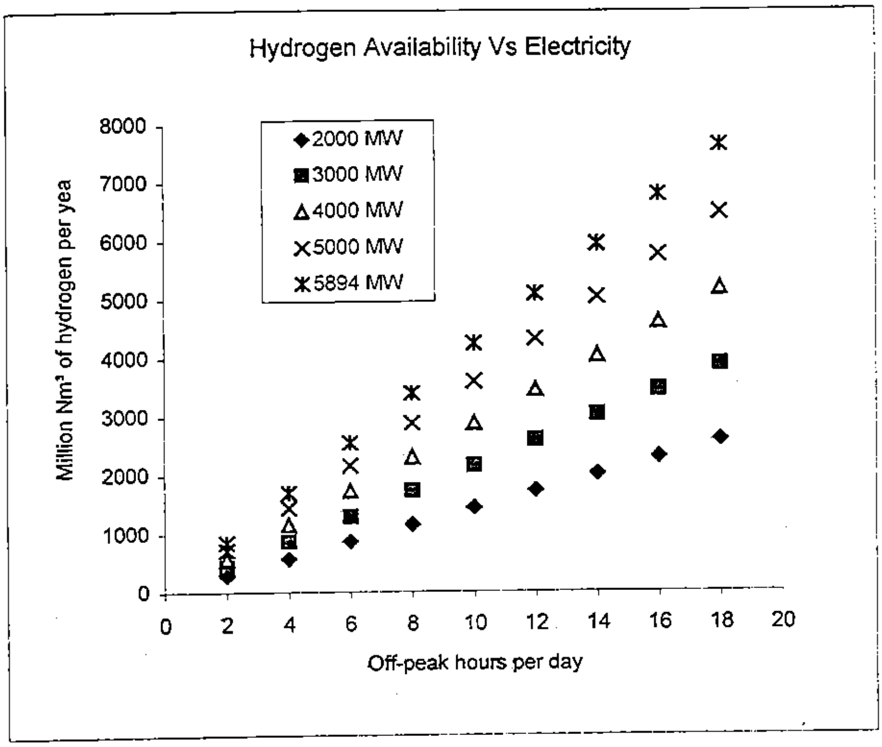

Figure 2.1 The availability of hydrogen at different power capacities and varying duration of off peak period

The availability of hydrogen at different power capacities and varying duration of off-peak period is plotted in figure 2.1. The potential magnitude of the hydrogen varies from 288 Million Nm^3 to 7639 Million Nm^3.

Cost of hydrogen

The cost of hydrogen produced from electrolysis is calculated in Table2.6. The total capital investment cost is from literature and the cost of water is taken as Rs 4 per litre, which includes the treatment cost and cost of chemicals etc. The cost of electricity has been fake as Rs. 4 per unit. As the electricity rates for off-peak and peak periods are same for many states in the country the cost of hydrogen produced will be higher till the "time of day tariff" are introduced[#]. The costs were calculated using an interest rate of 15% and plant life of 25 years.

[#] Some of the states in western region have introduced time of day tariffs.

Table 2.6 Cost of hydrogen produced from electrolyses

Plant capacity	
Product output (million GJ/year)	13
Total Capital investment (million	1649.05
Annual costs (million rupees/yr)	
Water	3270.40
Energy	2920
Other costs	329.81
Total annual cost (million rupees/yr)	6520.21
Annualised capital cost	255.109
Total annual expenditure (million rupees)	6775.20
Cost of production (Rs./GJ)	521.16
Cost of production (Rs./ Nm^3)	6.65

The cost of hydrogen at different electricity tariffs and at different water cost is plotted in Figure 2.2. The cheapest hydrogen cost will be Rs 2.432 / Nm^3, when the water cost is taken as Rs 2 per liter and electricity tariff are Rs 0.35/ kWh. Though water treatment cost may come down in near future but costs of electricity seem to be unachievable in foreseeable future.

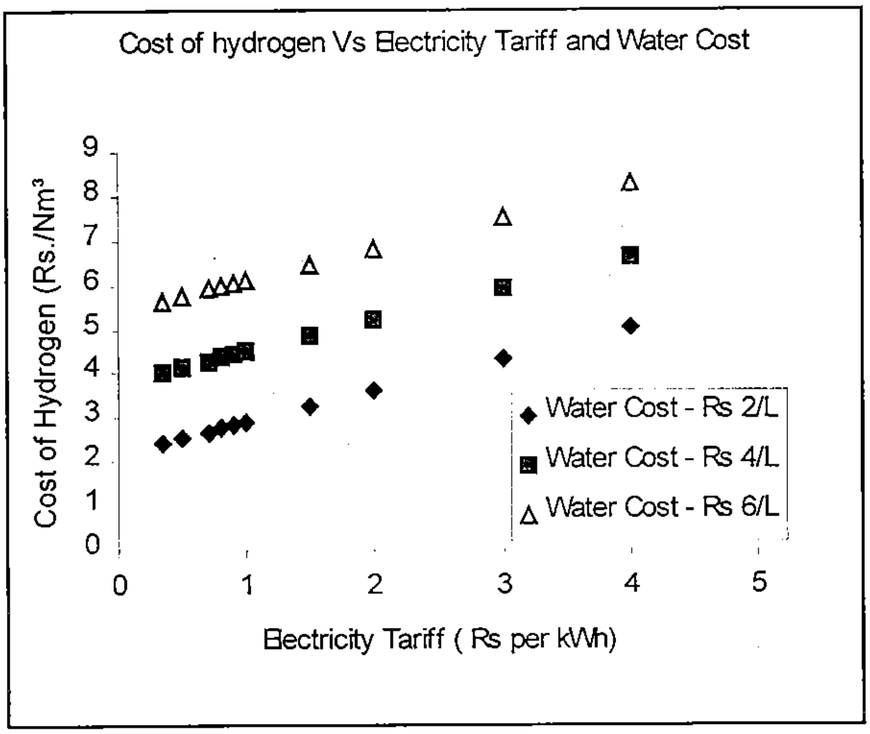

Figure 2.2 Cost of hydrogen at different electricity tariffs and at different water costs

Summary of tariff schedules of electric power supply utilities in India

Electricity tariff includes the following charges:

- Energy tariff (Rs./kWh) {details given in document "Average electric rates and duties in India" published by Central Electricity Authority}
- FCA (fuel cost adjustment) charges (Rs./kWh){details in CEA document}
- Demand charge (Rs./kW/month) for HT (33kV and above)
- Meter rent
- Electricity duty

The details of the tariff under these various heads for different user category in the states of New Delhi, Harayana and Uttar Pradesh are present in table .

Table 2.7 Electricity tariff of Delhi Vidyut Board - Domestic, 1997-98

Applicable to	Fixed charge Rs/KVA/Mth	Energy charges Kwh / Mth	Energy charges P/Kwh	Minimum charges Per month
Supply at 11000/400/230 volts				
1 Combined lighting / fans and power at single delivery point for residential consumers, hostels of recognised / aided Educational institutions, co-operative group housing societies and farm houses	Nil	0–100 units	100	Upto 1 Kw-Rs.50
		101–200 units	175	
		201–400 units	250	Above 1 Kw upto 2 Kw-Rs.100
		Above 400 units	300	Above 2 Kw -Rs. 60 Kw
2 Domestic lighting/fan and power on separate delivery points/meters :				
i. Domestic lighting/fan (LT)	Nil	0–100 units	100	-do-
		101–200 units	175	
		201–400 units	250	
		Above 400 units	300	
ii. Domestic power	Nil	All units	300	-do-
iii. For CGHS flats on 11 KV single delivery point		First 30% consumption	100	
		Next 30% consumption	200	
		Next 30% consumption	250	
		Remaining 10%	300	-do-

Note. (1)The above is subject to increase by not more than 10% for loads upto 20 Kw to neutralise cost of escalation w.e.f 1-4-1998 (2) For loads above 20 Kw full FAC is chargeable. For 2(iii) Rebate of 15% is available on energy charges (3) All dispensaries and hospitals run / aided by MCD are also charged tariff at domestic category

Source. DVB notification 1998

Table 2.8 Electricity tariff of Haryana Vidyut Prasaran Nigam Limited – Domestic, effective from 15-06-1998

Applicable to		Fixed charge Rs/KVA/Mth	Energy charges Kwh / Mth	P/Kwh	Minimum charges Per month
Supply at 11000/400/230 volts					
1	Lights and fans, domestic Pumping and household Appliances for single private Houses, hostels flats	Nil	If consumption in any month is upto 40 units only		Upto 1 Kw-Rs.20 Above 1 Kw upto 10 Kw-Rs.20 + Rs.10/Kw
			Upto 40 units	191	Above 10 Kw-Rs.110+Rs.15/Kw
			If consumption is above 40 units		Upto 1 Kw-Rs.25 1 Kw upto 10 Kw-Rs.25+
			Upto 40 units	191	Rs.12/Kw
			Above 40 units	306	Above 10 Kw-Rs.133+Rs.20/Kw
2	Bulk domestic supply	Nil	All units	277	Rs.70/kVA

Note. (1) Rates are inclusive of fuel surcharge of 41 P/Kwh (2) Electricity duty @10P/Kwh is chargeable

Source. HVPN's letter dated 3-9-98

Table 2.9 Electricity tariff of Uttar Pradesh State Electricity Board – Domestic, effective from 25-01-1998

Applicable to		Fixed charge Rs/KVA/Mth	Energy charges Kwh / Mth	P/Kwh	Minimum charges Per month
Supply at 400/230 volts and D.C at 440/220 volts					
	Domestic lights, fans, power and household appliances				
1	Rural area (upto 2 KW) (Population upto 10,000)	Rs.52/- per connection per month	All units	Nil	
2	Registered residential societies (upto 20 houses)	-	All units	220	Rs.95/KW
3	In other cases		1-100 units	180	Rs.110/-KW upto 2 KW
			101-300 units	210	Rs.105/-KW upto 5 KW
			301-500 units	235	Rs.100/KW upto 10 KW
			Above 500 units	260	95/ KW above 10 KW

Note : (1) A rebate of Rs.2/- connection is admissible for tariff at (1) above if the bills are paid within due date and surcharge of Rs.1/connection is levied after two months from due date. For tariff under (2) & (3) rebate is 10 Paise/Kwh and surcharge @15%. (2) A development rebate @50% on the amount of bill is given to new consumers for a period of 5 years in the hill district of UP. This rebate is not admissible to Central/State departments /offices/ undertakings. The hill districts are Almora, Pithoragarh, Chamoli, Uttar Kashi, Pauri Garhwal (excluding Kotdwara), Nainital (excluding Haldwani, Rudrapur, Gadarpur, Kashipur, Bajpur, Ramnagar, Jaspur, Khatima and Sitaganj Blocks), Tehri Garhwal (excluding Munoki Reti and Dhalwala Village under Narendra Nagar Block), and Dehradun District (excluding Doiwala, Raipur, Sahaspur and Vikas Nagar Blocks) (3) In case of D.C supply 25% extra shall be charged on above rates. (4) If supply is given above 400 Volt, a rebate of 5% is admissible.

Source. Board's letter dated 19-4-1999.

Table 2.10 Electricity tariff of Delhi Vidyut Board - Commercial, 1997-98

Applicable to	Fixed charge Rs/KVA/Mth	Energy charges Kwh / Mth	P/Kwh	Minimum charges Per month
Supply at 11000/400/230 volts				
1 For individual consumers in Conforming area or with NOC with connected load upto 100 Kw & energy consumption upto 200 units/Kw at 400/230 volts	Nil	Single phase All units	300	Rs.200/KW
		3-phase All units	400	
2 For all other than above including farm houses	Nil	All units	500	Rs.250/Kw
3 Non-domestic power at 11 KV	Nil	All units (Rebate 15% on energy charges)	350	Rs.200/Kw
4 Mixed load for heating lighting & power appliances in domestic and non-domestic establishments including DDA/MCD/ pumping loads of Delhi water supply and sewage disposal undertaking at 11 KV/400 volts				
i. -do- (LT)	Rs.200/KVA	All units	450	200/KVA
ii. -do- (HT)	Rs.150/KVA	All units	350	150/KVA

Note. (1) For all consumption in excess of the prescribed normative consumption, a surcharge of 30% shall be levied on the energy charges (2) Fuel and power purchase cost adjustment charge is applicable (3) All dispensaries and hospitals run/aided by MCD charged at domestic rates.

Source. DVB notification 1998

Table 2.11 Electricity tariff of Haryana Vidyut Prasaran Nigam Limited - Commercial, effective from 15-06-1998

Applicable to	Fixed charge Rs/KVA/Mth	Energy charges Kwh / Mth	P/Kwh	Minimum charges Per month
Supply at 11000/400/230 volts				
1 Lights, fans, appliances and small motors in all business house, clubs, cinemas, schools, hospitals, hostels etc	–	All units	392	Upto 1 Kw-Rs.60 Above 1KW-upto 20 Kw Rs.60+Rs.48/Kw or part thereof Above 20 Kw Rs.972+Rs.60/Kw or part thereof
2 Bulk supply	–	All units	359	Rs.70/KVA
3 Village chaupels	–	1st 40 units	191	Rs.25
		Above 40 units	306	

Note. (1) Rates are exclusive of fuel surcharge (2) Electricity duty @10 P/Kwh (Except for (iii) above)

Source. HVPN's letter dated 3-9-98

Table 2.12 Electricity tariff of Uttar Pradesh State Electricity Board – Commercial, effective from 25-01-1999

Applicable to	Fixed charge Rs/KVA/Mth	Energy charges Kwh / Mth	Energy charges P/Kwh	Minimum charges Per month
Supply at 11000/400/230 volts				
1 Lights, fans, power in shops , pvt hospitals, nursing homes, hotels, dispensaries, restaurants, guest houses, marriage house, show rooms commercial establishments railways, cinema theaters, X-ray plant, commercial institute, museum 400/230 volts or DC supply etc.				Rs.175/- KW upto 2 KW Rs.325/- KW upto 5 KW Rs.300/KW upto 10 KW Rs.275/- KW load upto 10 KW Rs.480/KW for balance
1. Rural area load upto 2 KW	Rs.80/ Connection	All units	Nil	
2. In other cases	Nil		425	

Note : (1) A rebate of Rs.2/- connection is admissible for tariff at (1) above if the bills are paid within due date and surcharge of Rs.1/connection is levied after two months from due date.. (2) A development rebate @50% on the amount of bill is given to new consumers for a period of 5 years in the hill district of UP. This rebate is not admissible to Central/State departments /offices/ undertakings. The hill districts are Almora, Pithoragarh, Chamoli, Uttar Kashi, Pauri Garhwal (excluding Kotdwara), Nainital (excluding Haldwani, Rudrapur, Gadarpur, Kashipur, Bajpur, Ramnagar, Jaspur, Khatima and Sitaganj Blocks), Tehri Garhwal (excluding Munoki Reti and Dhalwala Village under Narendra Nagar Block), and Dehradun District (excluding Doiwala, Raipur, Sahaspur and Vikas Nagar Blocks) (3) In case of D.C supply 25% extra shall be charged on above rates. (4) If supply is given above 400 Volt, a rebate of 5% is admissible.

Source. Board's letter dated 19-4-1999.

Table 2.13 Electricity tariff of Delhi Vidyut Board – L.T industry, 1997-98

Applicable to	Fixed charge Rs/KVA/Mth	Energy charges Kwh / Mth	Energy charges P/Kwh	Minimum charges Per month
Supply at 11000/400/230 volts				
1 Small industrial consumers including lighting heating and cooling load (upto 100 KW)				
i. 300 units/KW/month for non-continuous industries		All units	300	Rs.200/KW
ii. 400 units/KW/month for continuous industries		All units	300	-do-
2 For other industrial activity without valid municipal licence				
i. 300 units/KW/month for non-continuous industries		All units	400	Rs.300//KW
ii. 400 units/KW/month for continuous industries		All units	400	-do-

Note. For consumption in excess of prescribed normative consumption a surcharge of 30% is levied on energy charges in excess of normative consumption (2) 25% discount on energy charges is allowed to industrial consumers who shift their operations from day to night shift between 2100 hrs to 5.30 hrs (3) FAC is applicable.

Source. DVB notification 1998

Table 2.14 Electricity tariff of Haryana Vidyut Prasaran Nigam Limited – L..T industry, effective from 15-06-1998

Applicable to	Fixed charge	Energy charges		Minimum charges
	Rs/KVA/Mth	Kwh / Mth	P/Kwh	Per month
Supply at 11000/400/230 volts				
1 L.T industrial consumer (upto 70 KW)	–	All units	392	Rs.60/KW or part thereof

Note. (1) Tariff is inclusive of fuel surcharge of 41 Paise/KWH (2) The consumption of banafide factory lighting shall be included for billing at this tariff.

Source. HVPN's letter dated.3-9-98

Table 2.15 Electricity tariff of Uttar Pradesh State Electricity Board – L.T industry, effective from 25-01-1999

Applicable to	Fixed charge	Energy charges		Minimum charges
	Rs/KVA/Mth	Kwh / Mth	P/Kwh	Per month
Supply at 400/230 volts AC and 440 volts DC				
1 Small power(load upto 25 BHP)	Rs.28/BHP	All units	360	Rs.250/BHP
2 Medium power industry (Load 35 BHP-100 BHP)				
a. Non-continuous process peak hour restricted; Category	Rs.40/BHP	All units	390	Rs.300/BHP
b. Continuous process peak hour exempted category	Rs.50/BHP	All units	395	Rs.445/BHP
3 For connection in rural area getting supply as per rural schedules	10% rebate on the total amount of bill on the rates in (1) or (2) above			

Note: 1. In case of D.C supply 25% extra shall be charged on above rates (2) A development rebate @33.3% on the bill for new connection for a period of 5 years in Almora, Pithoragarh, Chamoli, Uttar Kashi, Pauri Garhwal, Tehri Garhwal, Nainital and Dehradun Districts of UP hill area (3) Fund adjustment of minimum charges shall be made in the final bill of the year (4) A rebate of 10 paise/Kwh is admissible for tariff 1,2 and 3 above if the bills are paid within due date, and surcharge of 1.5% per month is levied after one month from due date (5) If supply is given at 400 volts, a rebate of 5% is admissible (6) A rebate of 5%, 7.5% or 10% is given if voltage of supply is between 11-66 KV, above 66, 132 KV and above 132 KV respectively.

Source. Board's letter dated 19-04-99

Table 2.16 Electricity tariff of Delhi Vidyut Board – H.T industry, 1997-98

Applicable to	Fixed charge	Energy charges		Minimum charges
	Rs/KVA/Mth	Kwh / Mth	P/Kwh	Per month
Supply at 11000/400 volts				
1 Large industrial consumers (load above 100 KW) (At 11 KV)	Rs.150/KVA	All units	300	Rs.150/KVA
2 -do- (At 400 volts)	Rs.200/KVA	All units	400	Rs.200/KVA

Note. (1) For supply at a voltage of 33 KV or 66 KV at the discretion of the Board, the consumer shall be entitled for a rebate of 2.5% on 11 KV rates (2) A surcharge of 30% is levied if demand exceeds committed load (3)Supply at medium voltage may be given but tariff shall be higher by 10% (4) Billing demand shall be highest of the (I) maximum demand, (ii) 75% of the contract demand (iii)60% of the connected load (5) Industrial consumers who change over to operations to night shift between 21.00 to 05.30 hrs are entitled for 25% discount on energy consumption.

Source. DVB notification 1998

Table 2.17 Electricity tariff of Haryana Vidyut Prasaran Nigam Limited – H.T industry, effective from 15-06-1998

Applicable to	Fixed charge	Energy charges		Minimum charges
	Rs/KVA/Mth	Kwh / Mth	P/Kwh	Per month
Supply at 11000/400/230 volts				
1 Load above 70 KW				
i. Large industrial power Supply	–	All units	392	(i) Rs.70KVA
ii. Mini steel plants & steel Rolling, calcium carbide / Ferro silicon units & arc / Induction furnace		All units	392	(ii) Rs.140/KVA
iii. Lift irrigation	–	All units	208	(Rs.80/KW subject to
iv. Bulk supply		All units	392	minimum of Rs.575/months)
v. Street lighting		All units	392	

Note. (1) Rates are inclusive of fuel surcharge of 41 P/unit (2)The above tariff covers supply at 11 KV. A rebate of 1.5% shall be allowed for supply at 33 KV, 2% for supply at 66 KV, 2.5% for supply at 132 KV and 3% for supply at 220 KV and above (3) In case supply is metered on L.T side, the energy consumption shall be increased by 3% (4)For power factor below 0.85, surcharge for low power factor shall be levied (5) All consumption for bonafied factory lighting including those for canteen, hospital, factory street light, factory staff quarters and shopping centre and included under the above tariff (5) Steel Furnace surcharge @ 15 P/unit.

Source. HVPN's letter dated 3-9-98

Table 2.18 Electricity tariff of Uttar Pradesh State Electricity Board – H.T industry, effective from 25-01-1999

Applicable to	Fixed charge Rs/KVA/Mth	Energy charges Kwh / Mth	P/Kwh	Minimum charges Per month
Supply at 11 KV				
1 Arc induction furnaces (load Above 100/BHP) at 400 volt And above				
a. Induction furnaces	Rs.700/KVA	All units	100	900/KVA
b. Arc furnaces	Rs.615/KVA	All units	100	790/KVA
c. Rolling,re-rolling mills	Rs.440/KVA	All units	100	565/KVA
2 Large and heavy power industrial consumer (load above 100 BHP)				
i. For non-continuous Process	Rs.125//KVA	All units	370	Rs.380/KVA
ii. For continuous process	Rs.150/KVA	All units	390	Rs.600/KVA
3 Railway traction at 132 KV or below	Rs.125/KVA	All units	375	Rs.585/KVA
4 Floriculture & mushroom process (Load above 75 KW and 400 Volts or above)	-	All units	275	Rs.300/KVA

Note : 1. Minimum charges will be at the rate given above, but adjustment will be made in the last bill of year of account (2) A rebate of 5%, 7.5% or 10% is given if voltage of supply is between 11-66 KV above 66-132 KV and above 132 KV respectively (3) Fuel surcharge is applicable (4) The consumers shall be required to pay 10% extra on the amount calculated if supply is at 400 Volt (5) A surcharge of 1% of each .01 fall power factor between 0.85 upto 0.80 and 2% for each 0.01 fall below 0.80 upto 0.75.

Source. Board's letter dated 19-04-99

3 Hydrogen from natural gas and coal

Natural gas

Hydrogen from natural gas

Natural gas is steam reformed, followed by carbon monoxide shift reaction to obtain hydrogen. Steam reforming involves reaction of natural gas with steam to obtain hydrogen, carbon monoxide and carbon dioxide. The carbon monoxide is subsequently converted to carbon dioxide and hydrogen through shift converters. The remaining carbon di-oxide and any unreacted carbon monoxide or methane are then removed to obtain hydrogen of appropriate purity (Figure 3.1). This is typically done through PSA (Pressure Swing Adsorption).

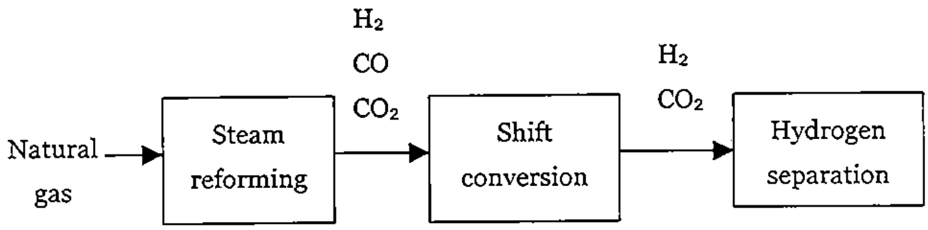

Figure 3.1 Conversion of natural gas to hydrogen

Natural gas availability

The details of the location and magnitude of natural gas generation in India is shown in Table 3.1. The gas produced by Oil & Natural Gas Commission Limited & the Joint Venture consortiums is marketed by the Gas Authority of India Ltd.(GAIL). The gas produced by OIL is marketed by OIL itself, except in Rajasthan where GAIL is marketing its gas. Gas is allocated to consumers by this Ministry on the recommendations of Gas Linkage Committee (GLC) which is an inter-Ministerial Committee with representatives from the Planning Commission and the Ministries of Finance, Power, Chemicals & Fertilizers and Steel.

In New Delhi, GAIL has formed a joint venture with Bharat Petroleum Corporation Limited for retail selling of natural gas for domestic applications through pipelines and for selling compressed natural gas (CNG) for automotive applications. The name of the joint venture is Indraprastha Gas Limited (IGL).

The current levels of natural gas generated in India are consumed for various energy and non-energy purposes. Table 3.2 shows the industrial consumption of natural gas, which excludes consumption of natural gas by ONGC. Further, there is additional demand for natural gas, leading to a natural gas deficit (in the 1992 itself, the registered amount with GAIL was larger than 260MMSCMD against expected production levelling of 85 MMSCMD[a]). The generation capacity in India is not expected to increase significantly, as there are no new fields. The generation from the fields of Tapti and Krishna-Godavri are expected to go up, but there are no quantified estimates.

Table 3.1 Natural gas production (million cubic meters) in India

Location	1997-98	1998-99
Onshore		
Gujarat	3115	3166
Assam/Nagaland	2018	2055
Arunachal Pradesh	24	24
Tripura	196	307
Tamil Nadu	95	107
Andhra Pradesh	1022	1218
Rajasthan	148	163
Offshore	19783	20388
Total	26401	27428

Source Annual report, Ministry of Petroleum and Natural gas

Table 3.2 Consumption of generated natural gas industry-wise (million cubic meters)

Industry	1997-98	1998-99
Energy purposes		
Power generation	8114	8714
Industrial fuel	3106	3005
Tea plantation	117	147
Domestic fuel	206	193
Captive use/LPG Shrinkage	569	911
Non energy purposes		
Fertiliser industry	8752	8869
Petro- chemicals	649	650
Others		
Total	21513	22489

[a] Official Web site, Ministry of Petroleum and Natural gas

The import of natural gas is being considered as an option through pipelines and as LNG (liquefied natural gas). The import of natural gas through pipelines from Iran, Bangladesh, Turkmenistan is uncertain due to political reasons. There are several proposals for the import of LNG and the details of a few LNG projects are shown in Table 3.3.

The future availability of natural gas would increase as a result of the imports but the future demand is also expected to go up. The future demand is expected to be 391 MMSCMD by 2025[a], while the availability from current projects is below that. Another issue is the cost of LNG which will be more expensive than the domestic natural gas.

Table 3.3 LNG project details

Project	Partners	Capacity, MT	Schedule
Dahej	ONGC, GAIL, IOC, BPCL	5	mid 2003
Kochi	Same as above	2	2006–2007
Pipavav	British Gas, Seaking Infrastructure Ltd.	2.5	
Dabhol	Enron, Bechtel, GE	5	mid 2002
Trombay	TEC, Total Gas and Power India, GAIL	3	Not finalized

Currently there is no surplus natural gas available. The availability of natural gas for hydrogen production would depend on allocation of existing natural gas. In Delhi, 0.15 MMSCMD has been allocated for transportation for CNG vehicles and is expected to increase further. A fleet of 10 fuel cell buses will require only a very small portion of that quantity (~ 0.00065 MMSCMD).

The natural gas available from western India is distributed to the northern states through Hazira – Bijaipur – Jagdishpur (HBJ) pipeline which passes through industrial regions of about 4 major northern states. The gas available on this HBJ pipeline contains 70 –80% of methane. The composition of the natural gas is given in Table 3.4.

Table 3.4 Natural gas composition available at HBJ pipeline

Methane	77-88%
Ethane	4-8%
n-butane, iso-butane, propane, hexane	0.5-2%
CO2	2.2-8.4%
Nitrogen	0.3-2%
Hydrogen sulphide	nil - 180 ppm

[a] The Financial Express, dated April 6, 2000

Magnitude of hydrogen from natural gas

Each mole of natural gas when completely oxidised, can yield four moles of hydrogen. In a real system due to losses, the amount is lower. The magnitude of hydrogen produced from natural gas is therefore taken from literature. The energy ratio (energy of product hydrogen/energy of natural gas feedstock) for the production of hydrogen from natural gas is assumed to be 0.897, when only the feedstock for hydrogen production is considered. When the heat and electricity requirements are considered, the ratio is 0.844. Therefore, the volume of hydrogen per Nm^3 of natural gas is in the range 2.77-2.61 Nm^3 for heating values of 39.51 MJ/Nm^3 for natural gas and 12.77 MJ/Nm^3 for hydrogen.

Cost of hydrogen from natural gas

The calculation of cost of hydrogen is shown in Table 3.5. The capacity of the reformer, cost of equipment and other costs are taken from literature (Williams, Larson, Katofsky and Chen 1995). The cost of natural gas feedstock is taken as Rs 5/Nm^3 and the cost of electricity is taken as 4 rupees/kWh. The amount of feed and electricity required is taken from literature. The annualised capital cost is calculated assuming an interest of 15% and an equipment life of 25 years. The exchange rate is assumed at 1USD=43 Rupees.

Table 3.5 Cost of hydrogen production from natural gas

Plant capacity	
Feed input (million GJ/year)	21.29
Product output (million GJ/year)	19.09
Capital cost (million Rupees)	
Equipment	4797.90
Other costs	3898.30
Total investment (million Rupees)	8696.20
Annual costs (million rupees/yr)	
Feed	3017.57
Chemicals	110.94
Energy	625.59
Other costs	383.83
Total annual cost (million rupees/yr)	4137.93
Annualised capital cost	1345.30
Total annual expenditure (million rupees)	5483.23
Cost of production (Rs./GJ)	287.23
Cost of production (Rs./ Nm^3)	3.67

The cost of hydrogen production as a function of natural gas price is shown in Figure 3.2.

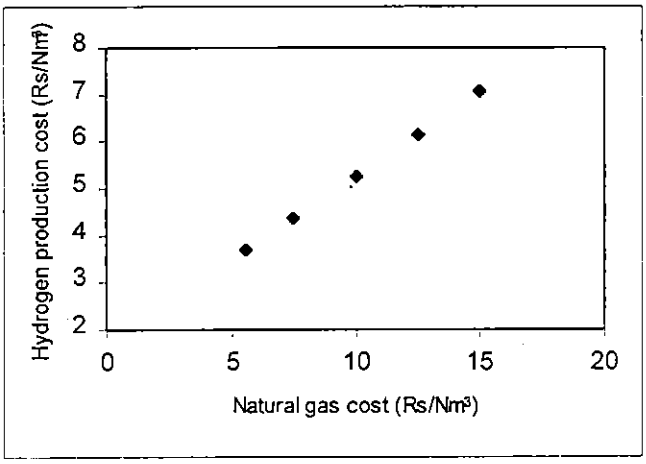

Figure 3.2 Cost of hydrogen production as a function of natural gas price

Natural gas for central hydrogen production plant

For operating commercial fleets of fuel cell buses in Delhi the central hydrogen production plant based on natural gas reforming, was envisaged. This section deals with site identification based on the availability of the natural gas and location of the local transport company (Delhi Transport Corporation) bus depots within Delhi. Possible Carbondioxide sequestration have also been suggested.

For the central hydrogen production plant based on natural gas reforming, site identification was done based on;

- Availability of natural gas pipeline in the area.
- Regulations for setting up a chemical processing industry in the area
- Distance of the central hydrogen production plant in the area from different DTC depots

Indraprastha Gas has indicated that there are no industrial areas within Delhi which have natural gas connection. However, in the outskirts of Delhi, there are industrial areas in Ghaziabad (in the state of Uttar Pradesh, northeast of Delhi) and Faridabad (in the state of Haryana, southeast of Delhi) which have natural gas connection. These could be potential sites. An estimate of distance between DTC bus depots and these areas are listed in Table 3.6. These are the estimated road distances.

Table 3.6 Distance of DTC bus depots from centralized natural gas based hydrogen production facility

Depots of DTC	Distance[a] of depots from the Central Hydrogen Plant	
	Faridabad	Ghaziabad
Rural Region		
1. Peera Garhi	59 km	40 km
2. Dichaon Kalan	63 km	65 km
3. Bawana	65 km	40 km
4. G.T. Karnal Road	54 km	29.5 km
5. Nangloi	63 km	41.5 km
	North Region	
1. Banda Bahadur Marg-II	46 km	22 km
2. Wazirpur-I	49 km	26 km
3. Wazirpur-II	49 km	26 km
4. Wazirpur-III	49 km	26 km
5. Rohini-I (Terminal)	54 km	36 km
6. Rohini-II	56 km	33 km
7. Rohini-III	53 km	37 km
	East Region	
1. Nand Nagri	48.5 km	12 km
2. Shahdra-II	46 km	9 km
3. Noida	30 km	12.5 km
4. Gazipur Depot	41 km	11 km
	South Region	
1. Okhla-I	26 km	25 km
2. Ambedkar Nagar-II	29 km	28 km
3. Kalkaji	26 km	25 km
4. Sarojini Nagar	36 km	23 km
5. Vasant Vihar	38 km	31 km
	West Region	
1. Maya Puri	45 km	35 km
2. Naraina	49 km	32 km
3. Shadipur	49 km	33 km
4. Hari Nagar-I	46 km	36 km
5. Hari Nagar-II	46 km	36 km
6. Hari Nagar-III	46 km	36 km
7. Keshopur	53 km	42 km
Interstate		
1. Indra Prastha Depot	34 km	15 km
2. Banda Bahadur Marg Depot-I	46 km	24 km
3. Yamuna Vihar Terminal	39 km	17 km
4. Okhla-II	26.5 km	18 km
5. Shahdra-I	46 km	9 km
6. Patparganj Depot	42 km	15 km

[a] Distances are based on *Delhi & its Environs Map, Special Map Series by Department of Science & Technology.*

Location of the depots has been provided by Delhi Transport Corporation, IP Depot.

The CO_2 sequestration site options closest to the city of Delhi are listed in Table 3.7

Table 3.7 CO_2 sequestration sites

Disposal option	Site	Distance from Delhi
Aquifiers	Himalayan belt	More than 500 km
Coal mine	Singrauli	900 km
Oil/ gas well	North/ south Gujarat	600 + km

The location of the 34 bus depots of DTC has been shown in Figure 3.3

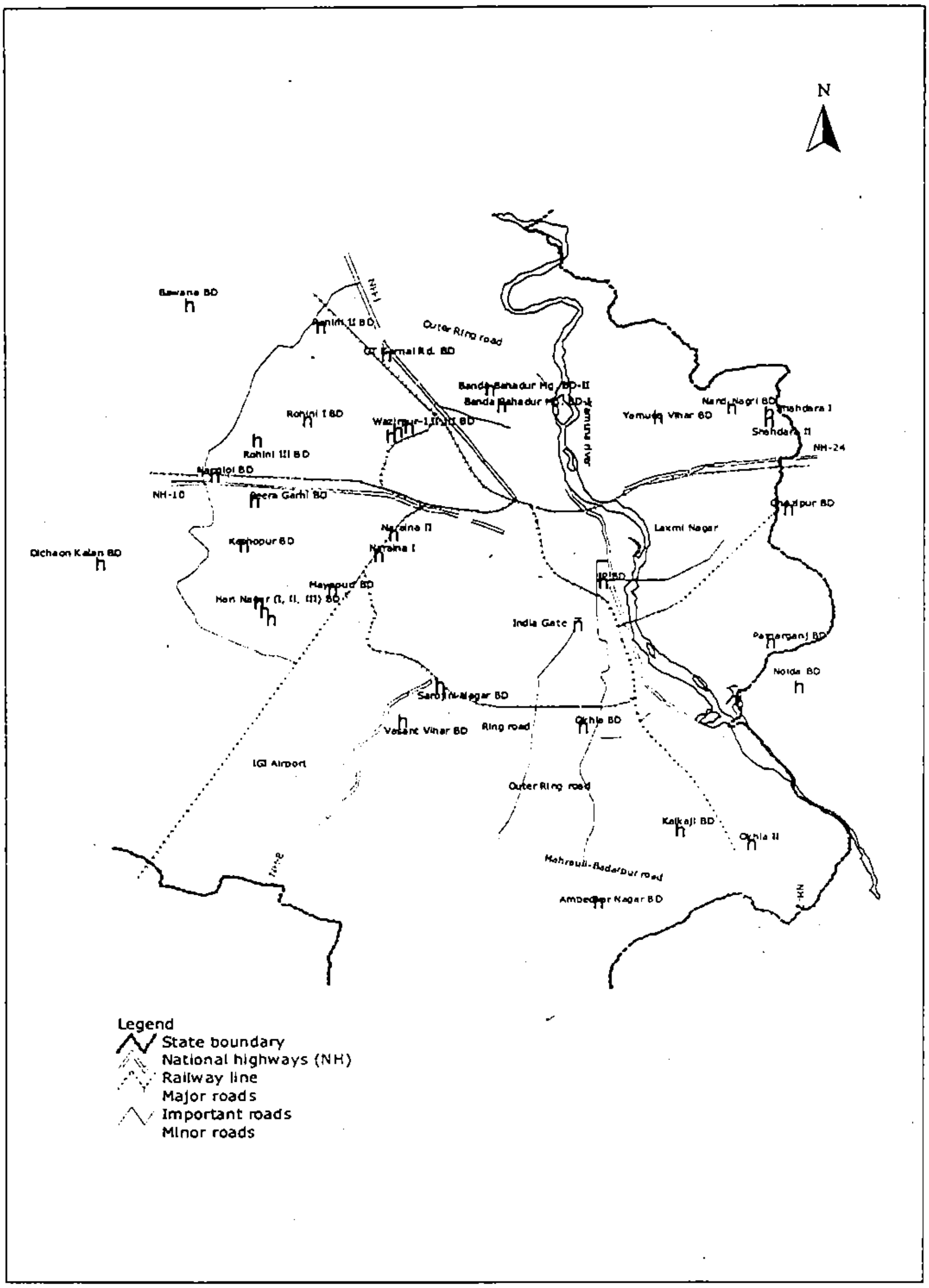

Figure 3.3 Location map of DTC bus depots.

Coal

Hydrogen from coal

To obtain hydrogen from coal, the coal is first gasified to produce a mixture of hydrogen, carbon monoxide and carbon di-oxide. The coal gas is cleaned to remove sulphur containing impurities after which the carbon monoxide is converted to carbon dioxide and hydrogen through shift converters. The remaining carbon di-oxide and any unreacted carbon monoxide are then removed to obtain hydrogen of appropriate purity (Figure 3.3).

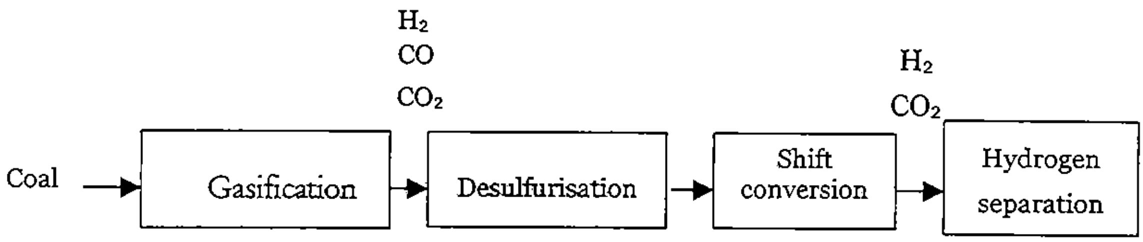

Figure 3.4 Conversion of coal to hydrogen

There are different technologies available for converting coal to coal gas such as Koppers-Totzek and Texaco. However, these technologies may not be suitable for Indian coal. BHEL has developed the technology for gasification of Indian coal. The composition of coal gas from these technologies is shown in Table 3.8.

Table 3.8 Coal gas composition from different gasification technologies

Component	Koppers-Totzek	Texaco	BHEL
Hydrogen	29	34	16.49
Carbon monoxide	60	48	13.47
Carbon di-oxide	10	17	13
Methane	–	–	0.95
N_2 and Ar	1	1	56.09

Coal availability

The details of coal production in India are shown in Table 3.9.

Table 3.9 Coal production during April-December 1998(million tonnes)

Company	Target	Actual production
Coal India Ltd	188.43	183.40
Singareni Collieries Company Ltd	21.80	18.32
Others	4.93	4.59
Total	215.16	206.31

Source. Annual report, Ministry of Coal

The coal currently produced is consumed for various applications. Table 3.10 shows the supply of coal by CIL and SCCL to various sectors.

Table 3.10 Supply of coal to various sectors by CIL and SCCL (1998-99) (million tonnes)

Sector	Actual offtake
Power	147.969
Steel	13.479
Loco	0.016
Cement	6.04
Fertilizer	3.009
Others	29.684
Colliery consumption	2.108
Total	202.305

However, India has large reserves of coal (Table 3.11), part of which can be utilised for hydrogen production. The reserve as of 1/1/99 was 208751.89 million tonnes including proven, indicated and inferred reserves[a].

Table 3.11 Coal resources of state (1 January 1999) (million tonnes)

State	Proved	Indicated	Inferred	Total
Andhra Pradesh	7094.82	3313.78	2928.67	13337.27
Arunachal Pradesh	31.23	11.04	47.96	90.23
Assam	259.37	26.83	34.01	320.21
Bihar	34401.00	28420.83	5934.77	68756.60
Madhya Pradesh	12502.72	21795.24	8474.47	42772.43
Maharashtra	3927.53	1357.37	1684.17	6969.07
Meghalaya	117.83	40.89	300.71	459.43
Nagaland	3.43	1.35	15.16	19.94
Orissa	9623.10	21990.91	17447.19	49061.20
Uttarptradesh	574.80	487.00	0	1061.80
West Bengal	10570.36	10981.29	4352.06	25903.71
Total	79106.19	88426.53	41219.17	208751.89

Magnitude of hydrogen from coal

Based on values in literature it is assumed that 1 tonne of coal can yield 1600-1800 Nm^3 of hydrogen (Williams, Larson, Katofsky and Chen 1995). One percent of the proven reserves (79106.19 million tonnes) in India can therefore yield 1265 billion Nm^3 of hydrogen which will be sufficient for 10,000 buses for 2000 years.

[a] TERI Data Directory and Year Book, 1999-2000

Cost of hydrogen from coal

The cost of hydrogen is calculated based on plant size and capital costs available in literature (Williams, Larson, Katofsky and Chen 1995) . The cost of coal is assumed as 400 rupees/tonne and the electricity cost as 4 rupees/kWh. The interest rate is assumed as 15% and the plant life as 25 years. The exchange rate is 1USD=43 rupees. The calculations are shown in Table 3.12.

Table 3.12 Cost of hydrogen production from coal gas

Plant capacity	
Feed input (million GJ/year)	48.79
Product output (million GJ/year)	37.76
Capital cost (million Rupees)	
Equipment	24272.21
Other costs	19721.17
Total investment (million Rupees)	**43993.38**
Annual costs (million rupees/yr)	
Feed	730.00
Chemicals	467.41
Energy	4204.22
Other costs	1699.05
Total annual cost (million rupees/yr)	**7100.68**
Annualised capital cost	6805.75
Total annual expenditure (million rupees)	13906.43
Cost of production (Rs./GJ)	368.28
Cost of production (Rs./ Nm³)	**4.70**

The cost of hydrogen as a function of coal price is shown in Figure 3.4.

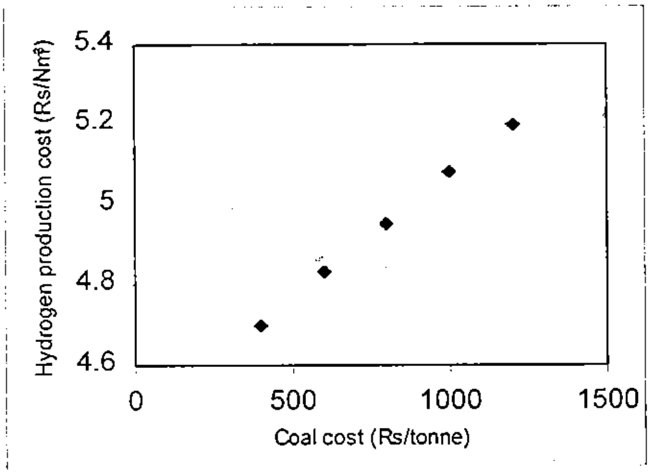

Figure 3.5 Cost of hydrogen production as a function of coal price

4 Hydrogen from biomass and waste

Conversion of biomass to hydrogen

Hydrogen is obtained from biomass by forming a gaseous fuel (biogas) which is subsequently cleaned and reformed (Figure 4.1). Steam reforming converts the methane to carbon monoxide and carbon di-oxide. Subsequently the carbon monoxide is converted to hydrogen and carbon di-oxide through shift conversion. Finally, the hydrogen is separated typically by pressure swing adsorption. Liquid fuels such as methanol and ethanol can also be obtained from biomass.

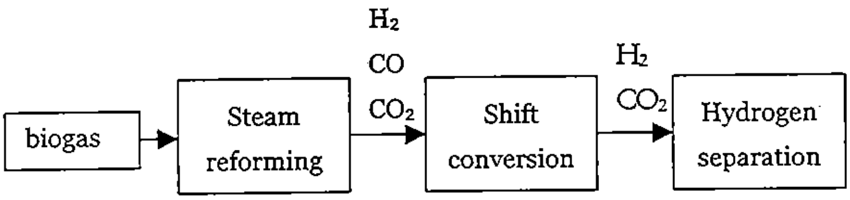

Figure 4.1 Conversion of biomass to hydrogen

There are different techniques for processing biomass and they can be broadly classified as dry chemical process and aqueous process. In the chemical process, the biomass is subjected to (a) Pyrolysis: where it is distilled in the absence of oxygen to yield oils / gasses and char or (b) Gasification in which biomass is partially oxidised at elevated temperatures to generate a combustible gas rich in carbon dioxide (CO_2), hydrogen, and some saturated hydrocarbons primarily methane.

In the aqueous process, alcoholic fermentation (e.g. production of ethanol) or anaerobic digestion can be carried out. In anaerobic digestion, organic matter is broken down by microbes to generate biogas (containing primarily methane and carbon dioxide) and sludge. This technique is suitable for biomass with large moisture content (municipal solid waste) and liquid wastes.

Biomass and waste generation

Biomass can be obtained from various sources such as forest sources, crop residues, and agro-industrial residues. In addition to these sources, there are various wastes from which biogas and hydrogen can be obtained such as distilleries, municipal solid wastes and municipal liquid wastes. Table 4.1 and 4.2 show the different sources and amount of biomass and waste that is generated in India.

Table 4.1 Type and amount of biomass generated (million tonnes/year)

Source of Biomass	Biomass Generated	Biomass Utilised	Biomass Available
Crop Residues	320	190—210	110—150
Agro Industrial Residues (excluding bagasse)	50	50	Nil
Forest Sources	35	Nil	35
Total	405	240—260	145—185

Source. MNES annual report

Table 4.2 Waste generation in India

Waste	Quantity
Municipal solid waste	27.4 million tonnes/year
Municipal liquid waste (121 class I & II cities)	12,145 million litres/day
Distillery (243 numbers)	8,057 kilo litres/day
Pressmud	9 million tonnes/year
Food & fruit processing waste	4.5 million tonnes/year
Willow dust	30,000 tonnes/year
Dairy industry waste (COD level 2 kg/m^3)	50-60 million litres/day
Paper & pulp industry waste (300 mills)	1,600 m^3 waste water/day
Tannery (2,000 numbers)	52,500 m^3 waste water/day

Source. Potential for energy generation from waste in India. *Bioenergy News*, 1(1). September 1996, pp 8–13

For metros of Delhi and Hyderabad, the sources of biomass/waste expected to be readily available include municipal solid waste, municipal liquid waste, industrial liquid waste and crop residues (e.g. paddy residue in Hyderabad and mustard residue in Delhi). The municipal solid waste generation is about 500 gms/day per capita and the sewage generation is about 150 litres/day per capita (Pachauri & Sridharan 1998).

Magnitude of hydrogen

Municipal Solid Waste

The calculation of the magnitude of hydrogen from MSW for India, Delhi and Hyderabad is shown in Table 4.3. It is assumed that half of MSW is available for hydrogen generation. The magnitude of hydrogen has been calculated using three technologies - BCL technology which uses thermal gasification (Larson, Worell and Chen 1996) ASTRA which uses anaerobic digestion and Wabio process which also uses anaerobic digestion. The process subsequent to gasification is assumed to be the same for all three processes. The biogas is cleaned to remove sulphur and halides. Subsequently the methane containing gas is steam reformed to produce a mixture of hydrogen, carbon monoxide and carbondioxide. This mixture is then passed through shift reactor to convert carbon monoxide to hydrogen through the water gas shift reaction. Finally the hydrogen is separated using pressure swing adsorption.

The biomass and hydrogen generation in the BCL process are taken from values reported in literature. For ASTRA and Wabio (Chhabria 1999) process, the biogas amount generated is taken from literature. It is assumed that biogas contains 70 volume % methane and 2.77Nm^3 of hydrogen can be recovered per Nm^3 of methane.

The magnitude of hydrogen generated per annum is in the range 200–400 million Nm^3 for Delhi and 100-250 million Nm^3 for Hyderabad.

Table 4.3 Magnitude of hydrogen from MSW

	India	Delhi	Hyderabad
Amount generated (million tonnes/year)	27.4	1.7	1
Amount available for hydrogen production (million tonnes/year)	13.7	0.85	0.5
Technology			
BCL			
Magnitude of hydrogen generated[a]	7096 million Nm^{3}pa	440 million Nm^{3}pa	259 million Nm^{3}pa
ASTRA			
Magnitude of biogas generated[b]	2740 million m^{3}pa	170 million m^{3}pa	100 million m^{3}pa
Magnitude of methane generated[c]	1918 million m^{3}pa	119 million m^{3}pa	70 million m^{3}pa
Magnitude of hydrogen generated[d]	5312 million Nm^{3}pa	329 million Nm^{3}pa	193 million Nm^{3}pa
Wabio			
Magnitude of biogas generated[e]	1712 million m^{3}pa	106 million m^{3}pa	62 million m^{3}pa
Magnitude of methane generated	1198 million m^{3}pa	74 million m^{3}pa	43 million m^{3}pa
Magnitude of hydrogen generated	3318 million Nm^{3}pa	205 million Nm^{3}pa	119 million Nm^{3}pa

[a]518 Nm^3 of hydrogen produced per tonne of MSW [b]200m^3 of biogas produced per tonne of MSW [c]70 volume % of methane assumed in biogas [d]volume of hydrogen assumed to be 2.77 times volume of methane [e]125m^3 of biogas produced per tonne of MSW

Distilleries

Distilleries generate 8057 kilo litres of waste per day. The composite distillery effluent contains a COD loading of 90–110gms/litre (Kansal, Balakrishnan, Rajeshwari, Lata and Kishore 1997). Assuming a COD reduction of 70% and a biogas yield of 0.5Nm^3/kg of COD degraded, the biogas yield is 0.282 million

Nm^3/day. Assuming a methane content of 65 volume percent, the hydrogen potential is ~0.45 million Nm^3/day.

Tannery

The composite wastewater of an Indian tannery contains COD loading of 3.4–5.1gms/litre (Kansal, Balakrishnan, Rajeshwari, Lata and Kishore 1997). Actual operating data from one of the tanneries showed a COD reduction of 70% with a biogas yield of ~0.2m^3/kg of COD removed and 80 volume percent methane. The waste from tanneries which amounts to 52,500m^3/day, has a hydrogen potential of ~0.06 million Nm^3/day.

Dairy

The composite wastewater of an integrated dairy contains 1.1–3.3 gms/litre COD loading (Kansal, Balakrishnan, Rajeshwari, Lata and Kishore 1997). Studies on simulated dairy waste water showed COD reduction of 90% with 0.4m^3 CH_4/kg COD. From the 50 million litres of dairy waste generated per day with a COD loading of 2 gms/litre, the methane generation is 0.036 million m^3/day and the hydrogen potential is ~0.09 million Nm^3/day.

Pulp and paper

The wastewater from pulp and paper mills contains COD of 250-500 mg/litre (Kansal, Balakrishnan, Rajeshwari, Lata and Kishore 1997). Data from actual plant operation showed 52% reduction in COD with biogas yield of 0.4m^3/kg COD reduced and 72% methane content. The 1600m^3/day of waste from pulp and paper mills have a generation potential of ~300 Nm^3/day of hydrogen.

Biomass

Each kilogram of biomass can yield 2–2.5 Nm^3 of producer gas. The gas contains a mixture of hydrogen, carbon monoxide and methane. The typical composition of the gas and the amount of hydrogen that can be recovered is shown in Table 4.4. The hydrogen is assumed to be recovered at 75%; the carbon monoxide is assumed to yield 0.75 times hydrogen (75% of theoretical capacity) and the methane is assumed to yield 2.77 times hydrogen. Therefore each tonne of biomass can yield 700 Nm^3 of hydrogen and the amount of hydrogen from 1% of available biomass is 1015 million Nm^3/year.

Table 4.4 Composition of producer gas and hydrogen available

	In 1 Nm^3	Hydrogen recovered
Hydrogen	0.2 Nm^3	0.15 Nm^3
Carbomonoxide	0.2 Nm^3	0.15 Nm^3
Methane	0.02 Nm^3	0.05 Nm^3
Total hydrogen from 1 Nm^3 of producer gas		0.35 Nm^3

Biogas potential in Delhi

Existing plants

The existing biogas plants in Delhi use sewage or cowdung (gobar) as the starting material and produce biogas through anaerobic digestion. The details of the location and capacities of the gobar gas plants and the sewage treatment plants are shown in Tables 4.5 and 4.6 respectively. The map of Delhi with the locations marked is shown in Figure 4.2.

Table 4.5 Location and capacities of gobar gas plants

Location	Capacities	
Ghazipur	140m^3/day (5 plants)	Composition
	85m^3/day (5 plants)	CH_4 ~60%
	85m^3/day (5 plants under construction)	CO_2 ~ 40%
	10 more 85m^3/day plants to be added	H_2S – trace
Jharoda	85 m^3/day (5 plants)	
	10 more 85m^3/day plants to be added	Current utilization
Nangli	85 m^3/day (5 plants)	Household cooking
	More plants to be added	

Source Personal communications, Delhi Energy Development Authority

Table 4.6 Location and capacities of sewage treatment plants

Location	Capacities (approx)	
Okhla	10,000 m^3/day	Composition
Keshopur	5070 m^3/day	Methane : ~63%
Rithala	2800 m^3/day (2800 m^3/day to be added)	CO_2: ~36%
Coronation Pillar	2800 m^3/day	Air:0.62%
Kondli	3100 m^3/day	H_2S:0.28%
Narela	700 m^3/day	
Rohini	1050 m^3/day	

Source Personal communicatons, Delhi Jal Board

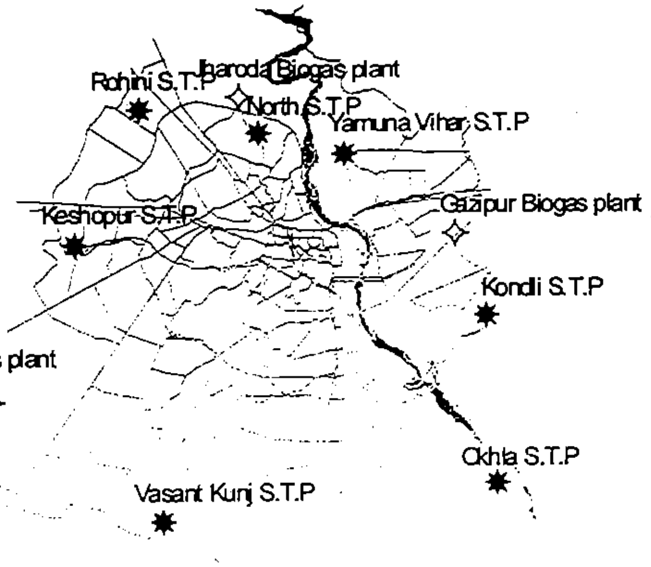

Figure 4.2 Biogas plants in Delhi

Potential from MSW

Currently, there are no existing commercial plants for generating biogas from MSW though some technologies are being tried on a smaller scale. Technologies that have been tested for Indian MSW are described below.

Biomass Plug Flow Digestors

Biomass plug flow digestors has been developed at ASTRA, Indian Institute of Science Bangalore for urban solid waste treatment. Table 4.7 shows some details of the digestor.

Table 4.7 Details of ASTRA plug flow digestor

Amount of organic fermentable matter		800-1000 kg/day
Biogas potential		150-200 m^3/day
Capital cost	Cost of biogas plant	Rs. 450000
	Cost of piping	Rs. 300000
Total		Rs. 750000
Annual A&M cost		Rs. 66000
Annual income	Biogas @ Rs. 3.75/m^3	Rs. 273750
	Organic manure @ Rs.730/ton	Rs. 137970
Total		Rs. 411720
Net income per year		Rs. 345820
Payback period (@15.5%)		2.84 years

Source Potential for energy generation from wastes in India, Bioenergy News, vol. 1, No.1, September 1996

Wabio process

Wabio process, developed by Ecotechnology JVV OY (Ecotec) of Finland is a one stage, medium concentration anaerobic digestion process operating in the mesophilic temperature range. The reaction produces a methane rich gas (60-65% methane, balance carbondioxide) and organic fertiliser. The biogas is typically used for power generation using gas engine generators. The advantages of the technique are lack of odours due to the reaction taking place in a closed vessel, minimal CO_2 emissions and the production of both energy and organic fertiliser.

Presently, there are two plants in operation using this technology. The first plant in Vaasa, Finland has been working since 1990. This plant treats 20,000 Tonnes per year of MSW and sewage sludge. The non-biodegradable portion is separated from the organic fraction and is incinerated. The organic fraction and sewage sludge are treated together in the Wabio AD plant. The electricity is fed to the grid and heat is used for domestic heating. The Bottrop plant in Germany has working since 1994 and treats 6500 tonnes per year of source separated wastes.

So far there is no such plant in India, although negotiations are in progress on couple of projects. A 150TPD plant MSW treatment plant is under consideration for Kalyan Dombivili Municipal Corporation to be set up by Nestler EcoTec Pvt. Ltd. Mumbai. The operation data obtained by analysis of the garbage from Kalyan Dombivilli is shown in table 4.8.

The investment[a] for a 200TPD plant is Rs. 25 crores (including biogas scrubbing to remove ammonia and other odour causing impurities, MSW feed sorting etc.) of which Rs. 6 Crores is the cost of the power generating unit. The annual running costs are Rs. 25 lakhs excluding the interest burden.

The annual revenue is generated from sale of electricity and compost, which work to Rs. 5.4 crores (1.7MW of electricity, 8000 hours/year @ Rs.4 per unit) and Rs. 4 crores (20,000 tpa @ Rs.2000 per tonne) respectively. Inspite of the attractive annual revenue, it is felt that a gate fee or subsidy would be required because the market for compost is not fully developed.

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[a] Personal communications with Mr. Chhabria, Nestler EcoTec Pvt. Ltd.

Table 4.8 Wabio AD plant operation details using Kalyan Dombivili garbage

Quantity of MSW to the plant	60,260 tpa
Quantity of mechanically separated biofraction	48,122 tpa
No. of operation days	300 d/a
Design capacity of the AD Plant	160 t/d
Inert reject separated from biofraction	2,5 t/d
Moisture content of biofraction	62%
Total Solid (TS) content of biofraction	38%
Volatile solids (VS) of TS	80%
Total quantity of VS to AD	14,089 tpa
Biogas production rate	550 m3/tVS
Biogas produced	77,37,950 m^3/a
Degradation rate of VS	57.5%
Biogas heat value	5.8 kWh/m^3
Electric power produced of biogas	17,054 MWh/a
Power consumption of the plant	1,500 MWh/a
Biohumus produced	27,132 tpa
Humus TS content	35%
Humus volume weight	850 kg/m3

Source Wabio anaerobic digestion process to produce energy from garbage, Bioenergy News, vol. 3, no.4, p. 13, September 1999

Cost of Biogas

The biogas generated in industries such as distilleries is currently used for generating power. If the biogas were to be diverted for other applications, the cost would have to compensate for the cost of buying the equivalent amount of power. Based on this, the cost estimate works to Rs.4/cu.m. This information was obtained based on discussions with the urban and industrial waste group at MNES.

The economic calculations for the ASTRA plug flow reactor as shown in Table 4.8 assume a rate of Rs. 3.75/m^3 for biogas. For a 200TPD Wabio AD plant, the annual revenue from electricity sale is ~ Rs. 5 crores. If the same revenue were to be generated from the sale of 20,000 m^3 per year of biogas, the cost works out to ~Rs. 6.8/m^3

Cost of hydrogen

The cost of hydrogen is shown in Table 4.9. The capacity of the reformer and cost of equipment is from literature. It is assumed that biogas as feed is available at Rs 4/Nm^3. In case of producer gas, the cost is assumed at Rs. 1/Nm^3. The annualised capital cost is calculated assuming an interest of 15%

and an equipment life of 25 years. The exchange rate is assumed at 1USD=43 Rupees.

Table 4.9 Cost of hydrogen production from biogas and producer gas

Plant capacity	Biogas	Producer gas
Feed input (million Nm^3/year)	375	1788
Product output (million Nm^3/year)	626	626
Capital cost (million Rupees)		
Equipment cost	2580	2580
Other costs	2096.25	2096.25
Total investment (million Rupees)	4676.25	4676.25
Annual costs (million rupees/yr)		
Feed	1500	1788
Chemicals	86	86
Energy	950.40	950.40
Other costs	206.40	206.40
Total annual cost (million rupees/yr)	2742.80	3030.8
Annualised capital cost	723.41	723.41
Total annual expenditure (million rupees)	3466.21	3754.21
Cost of production (Rs./ Nm^3)	5.53	5.99

The hydrogen production cost as a function of biogas and producer gas cost is shown in Figure 4.3.

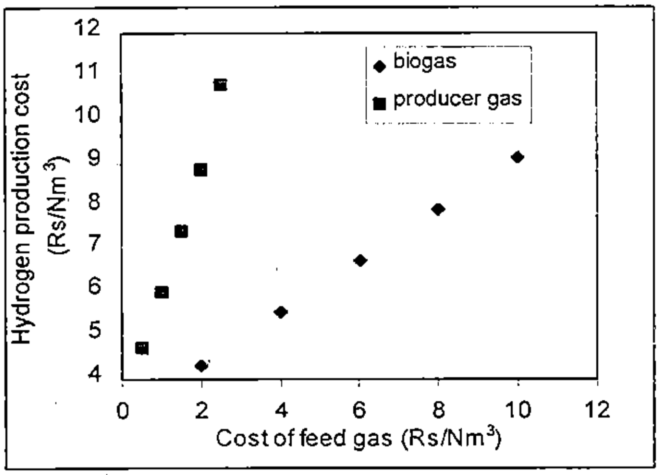

Figure 4.3 Hydrogen production cost as a function of feed cost

5 Hydrogen carriers

Methanol

Methanol is typically produced from naphtha or natural gas. The production of methanol in India in the recent years is shown in Table 5.1 and the demand-supply forecast is shown in Table 5.2.

Table 5.1 Production of methanol

Year	Production (thousand metric tonnes)
1995-96	350
1996-97	373
1997-98	396
1998–99	413

Source. CIER's handbook

Table 5.2 Demand supply forecast of methanol (tonnes per annum)

Year	1998-99	1999-2000[e]	2000-2001[f]
Total production	**366,615**	**369,000**	**390,000**
Assam Petrochemicals	34,000	35,000	36,000
Deepak Fertilisers	94,356	91,000	96,000
GNFC	139,759	167,000	168,000
National Fertilixzers	12,800	16,000	18,000
Rama Pterochemicals	32,000	14,000	24,000
RCF	47,700	46,000	48,000
Imports	103,000	160,000	165,000
Domestic Demand	**471,700**	**511,000**	**560,000**

[e]Estimated [f]Forecast

Source. Indian Chemical Manufacturer's Association

The demand for methanol is expected to grow at a steady rate from various sectors such as acetic acid, DMT, formaldehyde, pharmaceuticals and agrochemical sectors. It is expected that with requirement for MTBE (methyl tertiary butyl ether) and TAME (tertiary amyl methyl ether) in unleaded gasoline, methanol demand would increase further. However, due to high fuel costs, problems in availability of feedstock and overheads, the methanol producers are unable to compete leading to a shut down or scale down of production. To meet the methanol demand ~ 160,000 tonnes are expected to be imported during 1999–2000 and 30% of demand in 2000–2001 is expected to be met by imports. The Indian manufacturers are selling methanol at Rs. 7000–8500 per tonne, while the imports are available at Rs. 6000/tonne[a].

Methanol from natural gas

Magnitude of methanol

The energy ratio for conversion of natural gas to methanol is assumed to be 0.704. When the heating and electricity requirements are also considered the ratio is 0.674. Therefore, each Nm^3 of natural gas can yield 1.5-1.47 litres of methanol. The amount set aside for transportation sector in Delhi (0.15 MMSCMD) can yield 0.2 million litres of methanol per day.

Cost of methanol

The cost of production of methanol from natural gas is calculated in Table 5.3. The assumptions are the same as in case of hydrogen from natural gas.

Table 5.3 Methanol production cost from natural gas

Plant capacity	
Feed input (million GJ/year)	21.29
Product output (million GJ/year)	14.99
Capital cost (million Rupees)	
Equipment	5734.48
Other costs	4659.26
Total investment (million Rupees)	**10393.74**
Annual costs (million rupees/yr)	
Feed	3017.56
Chemicals	110.94
Energy	436.15
Other costs	458.75
Total annual cost (million rupees/yr)	4023.40
Annualised capital cost	1607.90
Total annual expenditure (million rupees)	5631.3
Cost of production (Rs/lt)	6.96

Methanol from coal gas

Magnitude of methanol

Each tonne of coal yields ~0.85 tonnes of methanol. Therefore, from one percent of the proven reserves of coal (79106.19 million tonnes), 670 million tonnes (957 billion litres) of methanol can be obtained.

[a] INFAC/ICMA (Indian Chemical Manufacturers Association)

Cost of methanol

The calculation of methanol production cost is shown in Table 5.4. The plant capacity and costs are from literature (Williams, Larson, Katofsky and Chen 1995). The cost of coal is assumed as 400 rupees/tonne and the electricity cost as 4 rupees/kWh. The interest rate is assumed as 15% and the plant life as 25years. The exchange rate is 1USD=43 rupees.

Table 5.4 Methanol production cost from coal gas

Plant capacity	
Feed input (million GJ/year)	48.76
Product output (million GJ/year)	31.66
Capital cost (million Rupees)	
Equipment	28322.81
Other costs	23012.28
Total investment (million Rupees)	51335.09
Annual costs (million rupees/yr)	
Feed	730
Chemicals	467.41
Energy	1237.33
Other costs	1982.60
Total annual cost (million rupees/yr)	4417.34
Annualised capital cost	7941.50
Total annual expenditure (million rupees)	12358.84
Cost of production (Rs./GJ)	390.36
Cost of production (Rs./litre)	7.23

Methanol from biomass and waste

Magnitude of methanol

It is assumed that each Nm^3 of methane can yield 1.5 litres of methanol. The volume of methane and the corresponding value of methanol from various waste sources is shown in Table 5.5

Table 5.5 Methanol from waste sources and biomass

Source	Methane potential (million Nm^3/year)	Methanol potential (million litres/year)
MSW	1116	1674
Distillery waste	60.6	90.9
Tannery waste	8	12
Dairy waste	11.8	17.7
Pulp and paper	0.04	0.06
Biomass (1%)		52

Cost of methanol

The calculation of methanol cost is shown in Table 5.6. The plant capacity and costs are from literature (Williams, Larson, Katofsky and Chen 1995). The assumptions are same as that made in hydrogen from biogas and producer gas.

Table 5.6 Methanol production cost from biogas

Plant capacity	
Feed input (million Nm^3/year)	222
Product output (million litres/year)	333
Capital cost (million Rupees)	
Equipment cost	4154.66
Other costs	3375.66
Total investment (million Rupees)	7530.32
Annual costs (million rupees/yr)	
Feed	888
Chemicals	71.81
Energy	221.06
Other costs	332.37
Total annual cost (million rupees/yr)	**1513.24**
Annualised capital cost	1164.93
Total annual expenditure (million rupees)	2678.17
Cost of production (Rs./ litres)	8.04

Ethanol

Ethanol in India is produced in distilleries by fermentation of molasses, which is a by product of the sugar industry. There are 290 distilleries in India with a total capacity of 2825 million litres per year (Table 5.7). However, the total consumption in India is only 1200 million litres per year leading to a surplus capacity of 1625 million litres. It has been estimated that upto 576.50 million litres can be made available by 2002 at a price of ~ Rs. 19 per litre[a]. The estimated supply of ethanol that can be available is shown in Table 5.8.

[a] All India Distiller's Association

Table 5.7 Distillery installation capacity in various states

State	No of distilleries	Installed capacity(Mltr/yr)
Andhra Pradesh	24	123
Assam	1	2
Bihar	13	88
Goa, Daman and Diu	6	15
Gujarat	10	128
Haryana	5	41
Himachal	2	3
J&K	7	24
Karnataka	28	187
Madhya Pradesh	21	469
Maharashtra	65	625
Nagaland	1	2
Orrisa	7	13
Pondicherry	3	11
Punjab	8	88
Rajasthan	7	14
Sikkim	1	7
Tamil Nadu	19	212
Uttar Pradesh	43	617
West Bengal	6	24

Table 5.8 Estimated supply of ethanol (million litres)

Region	Estimated supply available		
	1999-2000	2000-01	2001-02
Northern	165.00	177.40	190.70
Delhi	Total requirement will be supplied from northern region		
Western	220.50	237.00	254.80
Southern	108.30	116.40	125.20
Eastern	5.00	5.40	5.80
Grand Total	498.80	536.2	576.50

6 Fuel supply and refuelling infrastructure

As part of fuel cell bus introduction programme, Delhi and Hyderabad have been selected as candidate cities for demonstration of fuel cell buses. In this chapter hydrogen fuel demand for a fleet of fuel cell buses, fuel supply options and refuelling infrastructure requirement have been assessed. Fuel supply and refuelling system were assessed on the basis of the fuel demand. Fuel demand in turn was calculated from the vehicle fuel economy, annual mileage and number of vehicles in the fleet.

Fuel demand

The daily fuel demand for a fleet of fuel cell buses comprising of 10 buses was calculated on the basis of average kilometres logged by a city bus (Dehi/ Hyderabad). The fuel economy and range were assumed for Ballard's Phase II Fuel Cell Bus. The features of Ballard's Phase – II hydrogen fuel cell bus are described in Table 6.1. Based on the average kilometers logged by a city bus in Delhi/ Hyderabad, the annual hydrogen fuel demand per bus has been assessed as 2.29 Million Standard Cubic Fts.

Table 6.1 Characteristic of hydrogen fuel cell bus

Fuel economy[a]	32.5 scf H_2/ kilometer
Kilometers/day[b]	193 km
Kilometers/ year[c]	70445
Fuel Storage	H_2 gas @ 3600 psi
Hydrogen stored on board (scf)	13,000[a]
Range (kilometers)	400[a]
Energy use per year (GJ/year)	784
Hydrogen use per year (m scf/year)	2.29

[a] Based on the efficiency of Ballard Phase II PEMFC Bus [b] Daily kilometers logged by a Delhi Transport Corporation bus [c] Total annual mileage of a DTC bus operating 365 days of the year

For a fleet of fuel cell buses comprising of 10 buses the annual and daily fuel demand based on the hydrogen demand per bus has been calculated in Table 6.2. Annual hydrogen demand for operating fleet of fuel cell buses in Delhi will be 22.9 million scf. There will be an actual daily demand of about

0.063 million scf or 1692 Nm^3. The total demand including the compensation losses in storage and refilling etc. was assumed at 2000 Nm^3 per day.

Table 6. 2 Hydrogen demand for a fleet of fuel cell buses

No. of fuel cell buses in the fleet	10
Annual hydrogen demand per fuel cell bus	2.29 m scf
Annual hydrogen demand for fleet of fuel cell buses	22.9 m scf
Actual Hydrogen demand per day for operating fleet of FCBs	0.063 m scf
	1692 Nm^3
Energy use per day	21.61 GJ/ day
Total Demand (Including losses in storage/refilling etc.)	2000 Nm^3

Potential near term hydrogen supplies for cities of Delhi and Hyderabad.

All fuel cells currently being developed for near term use in road vehicles require hydrogen as a fuel. While hydrogen can be produced onboard the vehicle by reforming methanol or gasoline, direct storage of hydrogen has many attractive features. The vehicle is simpler in design, less costly and more energy efficient, refueling can be accomplished rapidly and hydrogen can be produced from many sources (Ogden, Steinbugler and Kreuts 1997). The relative simplicity of vehicle design is a trade-off against the added complexity and cost of developing a hydrogen-refuelling infrastructure. Initially this problem could be minimised by introducing hydrogen fuel cell buses into centrally maintained fleet where the cost of installing hydrogen-refuelling facilities could be averaged over a more number of vehicles.

Based on the level of fuel demand, availability of the appropriate technology, operational and maintenance requirement , literature survey , as well as experiences with other hydrogen refuelling demonstration projects carried abroad, the following production sources of hydrogen were identified.

- By-product hydrogen from industries
- On-site thermo-chemical conversion of natural gas
- On-site electrolysis

The suitability of the hydrogen source, issues and potential availability for meeting the fuel requirements of demonstration scale refuelling station in cities of Delhi and Hyderabad are compared in Table 6.3. The most suitable near term fuel supply options for a demonstration scale refuelling station in Delhi could be from a chemical industry where by-product hydrogen is available or from small scale on-site natural gas reformer. Though electrolysis path is also suitable as

Table 6.3 Near term fuel supply scenario in Delhi and Hyderabad

Production Option	Delhi			Hyderabad		
	Issues	Availability	Source	Issues	Availability	Source
By-product Hydrogen	■ Transport over long distances ■ Uncertainty in selling cost of hydrogen	■ 8000 Nm³/day	■ Punjab Alkalies & Chemical Ltd, Nangal, Punjab ■ Siel Chemicals, Patiala, Punjab	■ Transport of hydrogen over long distance. ■ High selling price of hydrogen , Rs 12-30 per Nm³ (As quoted in the questionnaire response)	■ 4000 Nm³/day	■ The Andhra Sugars Ltd., Kovvur, AP ■ Sree Rayalaseema Alkalies & Chemicals Ltd., Kurnool, AP
On-site reforming of NG	■ O & M requirements of NG reformers	■ 0.15 MMSCMD of NG has been allocated for transport sector.	■ Indraprastha Gas Limited, Delhi	■ Availability of Natural Gas	–	–
On-site Electrolysis	■ High costs owing to high electricity rates	----	■ Electricity Boards	■ High costs owing to high electricity rates		■ Electricity Boards

* Response to the questionnaire is still awaited

Presently there is no excess hydrogen but can be made available as and when required

electrolysers capable of delivering 35 to 3500 Nm^3/hour are commercially available(Stuart Energy System Inc, USA), but non-availability of cheap off-peak electricity in both the cities as well as high total capital investment associated with small capacity electrolysers will lead to a very high delivered cost of hydrogen. In Hyderabad, the availability of continuous availability of natural gas is uncertain, however there are two chlor-alkali plants in Kovvur and Kurnool which could be possible source of hydrogen. The cost of delivered hydrogen at the refuelling station has been calculated for direct hydrogen available from industry and for a small scale on-site reformer. The option of electrolysis has not been included in this report.

Direct production from industrial sites

The chlor-alkali plants closest to Delhi and Hyderabad have excess hydrogen available in the range 4000 – 10000 Nm^3/day, which is well above the daily requirement of the refuelling station catering to a fleet of 10 buses. The transport cost of hydrogen has been calculated in Table 6.4. For the transportation two cases were analysed one with compressed gaseous hydrogen and second with liquified hydrogen. The truck capacity and the capital cost were taken from literature, the distance of the chlor-alkali plant was assumed to be 500 km from the refuelling site. The annualised capital cost was calculated assuming an interest of 15% and an equipment life of 25 years. The transportation cost for gaseous hydrogen is Rs 5.50/Nm^3 against a liquified hydrogen transportation costs of Rs 8.15/Nm^3.

This is well in correlation to the fact that, transport of hydrogen as compressed gas is econmical for distances upto 500km whereas transport as liqiuified hydrogen is economical for large quantities and for distances upto 1600km[#].

The cost of by-product hydrogen delivered as compressed gas at refuelling station has been calculated in Table 6.5. The costs for storage of hydrogen in an above ground storage tank at refuelling station has been calculated at Rs 1.56/ Nm^3 (Padro and Putsche 1999) where as the compression and dispensing cost is Rs 0.32/ Nm^3.

[#] Personal communication with Air Products & Chemicals Inc., USA

Table 6.4 Transportation cost for hydrogen

	Compressed H_2	Liquefied H_2
Truck capacity (Nm^3)	1700	39140
Annual transport (million Nm^3/year)	0.6	0.7
Capital cost (million Rupees)	6.88	21.5
Running costs (million rupees/year)		
Fuel	1.82	0.09
Labour	0.18	0.18
Other costs	0.34	2.15
Annualised capital cost	1.06	3.32
Total annual expenditure (million rupees)	3.41	5.74
Cost of transport (Rs./ Nm^3)	**5.50**	**8.15**

Table 6.5 Delivered cost of compressed hydrogen from industrial site

Transport cost (Rs/ Nm^3)	5.50
Storage cost (Rs/ Nm^3)	1.56
Compressor + Dispensors (Rs/ Nm^3)	0.32
Selling price of hydrogen (Rs/ Nm^3)	3.50
Total (Rs/ Nm^3)	10.88

Onsite production of hydrogen from natural gas

The daily requirement of hydrogen for a fleet of 10 buses is 2000 Nm^3. Commercial reformers are expected to be available in the range 80 to 800m^3/hour[a]. The details of the plant costs, natural gas requirement and other costs are shown in Table 6.6. The costs are calculated based on two scenarios – onsite construction of a small reformer (0.18 tons/day) and factory manufactured small reformer of the same capacity. The cost are taken from literature (Thomas, Kuhn, James, Lomax and Baum 1998). It is to be noted that the actual costs of small reformers maybe different than this amount[1].

The only DTC depot, which has online natural gas supply, is the Sarojini Nagar depot. It is expected that the amount of natural gas required (~0.0008 MMSCMD) can be made available. If any other depot is chosen (e.g. Okhla depot as mentioned by Chairman, DTC), natural gas would have to be brought in.

[a] Praxair offers reformers in the range 80-800 m^3/h which can use flexible fuel such as natural gas as well as methanol.

Table 6.6 Plant capacity and cost for on-site hydrogen production from natural gas

	On-site	Factory built
Plant capacity (tpd)	0.18	0.18
Natural gas input (million Nm^3/day)	0.162	0.162
Hydrogen output (million Nm^3/day)	0.45	0.45
Capital cost (million Rupees)		
Reformer	67.94	8.17
Storage	10.58	3.01
Compressor	4.73	1.29
Total Investment	83.25	12.47
Running costs (million rupees/year)		
Feed	0.91	0.91
Energy	0.43	1.08
Other costs	6.79	0.82
Annualised capital cost	12.88	1.93
Total annual expenditure (million rupees)	21.01	4.73
Cost of production (Rs./ Nm^3)	46.69	10.52

Cost comparison of fuel supply options for Delhi and Hyderabad

The cost of delivered hydrogen transported as compressed gas from a chlor-alkali plant is estimated at Rs 10.88/ Nm^3. This cost is based on the hydrogen selling price of Rs 3.50/ Nm^3. This cost is competitive with the delivered cost of hydrogen of Rs 10.52/ Nm^3 from an on-site small scale factory built reformer. However the cost of delivered hydrogen from an On-site reformer constructed on-site at the refuelling station has been estimated at Rs 46. 69/ Nm^3. This cost is well above the delivered cost of hydrogen from a chlor-alkali plant. In case where the selling cost of hydrogen by the chlor-alkali is taken as the highest of Rs 20/ Nm^3, the delivered cost of hydrogen will be Rs 27.38/ Nm^3 well below that from the on-site reformer constructed on-site at refuelling station. It is suggested that for a small scale demonstration project, compressed gaseous hydrogen from a chlor-alkali plant could be the ideal option. However the safety issue and the approvals from Chief Controller of Explosive will be required for long distance transport.

Fuel station infrastructure requirement

Location/ siting

It is envisaged that the hydrogen refuelling station will be catering to the demand of 5 buses per day and the fuel in the buses will last for two operational days. For the safety aspects and convenience in refuelling it is suggested that refuelling station be positioned at bus depot of local Transport Corporation and where the fuel cell buses after each days trips will return. The Delhi Transport

Corporation has in principle agreed to provide space at Okhla Phase - I Depot, which may be used as depot for the fuel cell buses as well as for refuelling station. However the possibility of locating the refuelling station at another depot (Sarojini Nagar, Delhi) where online supply of natural gas is available may also be explored. But this is subject to clearance by Chief Controller of Explosives (or Oil Industry Safety Directorate) for use of such a space for storing / producing large quantities of explosive fuels like hydrogen.

Requirements of fuel station

The final design of the refuelling station will be decided after discussing the fuel supply options and technical / safety requirements of such a station with International Consultant. However, some of the basic requirements of a hydrogen refuelling station as collected from literature has been listed below:

- The station should be capable of refuelling fuel buses with hydrogen at a storage pressure of 3600 psi. The cylinder will be fixed on the roof of the bus and refilling will be done by equalisation of the pressure between the dispenser and the bus fuel tank.
- The station will have facilities for receiving, storing, processing and transferring hydrogen.
- The fuel to bus transfer will be via a fully automated dispenser.
- Trained personnel with training in the safe handling of hydrogen will perform the refuelling.
- The filling time, maximum delivery capacity of the refuelling system to achieve a settled storage pressure of 3600psi has to be confirmed with bus manufacturer as well from the demonstration projects carried abroad. [The Chicago Transit Authority's refuelling station could fuel three buses within a 2 hr period. It required a maximum delivery capacity of 2148 Nm^3 to achieve a settled storage pressure of 3600 psi at ambient conditions ranging from 0 to 100 F. The fuel consumption in the bus was about 537 Nm^3. The system was meant for a liquid hydrogen based fuel supply].

Safety factors

Hydrogen is characterised as explosive fuel therefore safety has to be a prime concern in its production, storage, transport and usage. The handling of explosives for various purpose has to be done under the guidelines laid down by Chief Controller of Explosives, Nagpur. At present hydrogen is transported via pipelines and cylinders but there are fixed codes for large scale transport of hydrogen in pressurised containers. These safety codes have to be laid down in consultation with CCE and Oil Industry Safety Directorate. The main prime hazards to be addressed in the refuelling infrastructure are;

- Fire
- Over pressurization of the storage tanks on the bus
- Movement of the bus while refuelling.

Other safety features that need to be looked into are;

- No open flames be allowed in the vicinity of hydrogen handling facility
- All electrical connection be properly grounded to avoid the possibility of leakage/ spark
- Required offsets of 75 feets from stored quantities of hydrogen to wall opening etc.
- Use of conventional leak detecting and fire prevention systems.
- Hydrogen like natural gas, is odourless and must have an odorant added so that it can be detected by the average person in the event of a leak.
- Hydrogen flame is virtually invisible when it burns, except in situations of a very low background lighting, and must have a luminant added to make the exposed flames visible.

Details of Indraprastha bus depot.

Indraprastha Bus Depot of Delhi Transport Corporation is located on the eastern side of the ring road and is used for stationing buses plying on interstate routes. The depot garage has the capacity of 80 buses.

Existing power supply at Indraprastha depot

The depot has a connected load of about 192kW supplied at 224 KVA.

Water availability at Indraprastha depot

Depot has two sources of water. The water for drinking purpose is supplied by Delhi Jal Board (DJB|). The quantity of water supplied depends upon the timings and the season. The DJB water costs are ~ Rs. 25/kilo liter. The total dissolved solids in the DJB water available at IP Depot were 0.15 - 0.2 ppm (parts per million). The other source is the sub-soil water which is pumped out from a tube well. This water is used for washing of buses and for sanitation purpose. There is no direct cost associated to this water. The data on quantity of tube well water utilized was not available however according to officials at IP Depot, the pumping electricity (Domestic Units) cost them Rs 8000 per month. The total dissolved solids of sub-soil water were 1.20 parts per million.

Design Philosophy for CNG stations in Delhi

The fuel supply/ distribution system adopted by Indraprastha Gas Limited for catering to CNG vehicles in the Delhi has been discussed in the following section. The inputs are based on the personal discussions with Mr A K Gumbhar, Head, CNG Projects, Indraprastha Gas Limited, New Delhi.

The design philosophy for setting up of CNG stations in Delhi is based on the infrastructure comprising of mother, daughter and online stations. The concept of mother, online and daughter stations has been adopted based on the availability of gas distribution network available at the respective stations. Both Mother and Online stations are provided with a continuous gas supply through pipeline connection. The supply of natural gas to these type of stations are taken from the transmission pipeline at the pressure available in the line which is then compressed to higher pressures with the help of compressors and then dispensed to vehicles. A mother station comprises of a bigger compressor and also provides the cascade filling which are permanently mounted on the platform of a Light Commercial Vehicle (LCV) and carried to a Daughter station. A Daughter station does not have a gas pipeline connection available for dispensing of CNG fuel. Another reason for adopting mother daughter station concept is the cost for laying of 4" steel pipeline for transporting natural gas with in the city which works out to apprx.Rs.2,500/Meter.

As the number of vehicles converting to CNG increase and the demand for CNG increases correspondingly, the capacity of the daughter stations and online stations could be upgraded with larger compressors. Gradually, as the distribution network infrastructure grows and covers the daughter stations more and more number of daughter stations will be converted to On-line stations.

There is no restriction as far as conversion of all online stations to mother stations is concerned. The main difference between a mother and a on-line station is that mother station fills mobile cascades also which are feeding daughter stations, fills heavy duty questionnaire vehicles like buses and has a bigger compressor and ultra fast filling dispenser. Thus all online stations can be changed over to mother stations by installing larger capacity compressors and dispensers. However, many factors are considered for setting up of a mother station like location of the station, throughput available from the station, location of daughter station and traffic volume etc.

CNG to daughter stations is transported in light commercial vehicle mounted cascades. Cascade is basically group of cylinders of required water capacity enclosed in structural frame having facility of lifting and placement. The amount of CNG that can be stored in cylinders of cascade depends upon the water capacity of each cylinder and availability of fuel pressure. The cylinders are manufactured from high quality seamless tubes.

For transport to stations with in Delhi, Indraprastha Gas Limited has procured the cascades of 2200 and 3000 liter water storage capacity cylinders. Each cascade is manifolded into three banks high pressure, medium pressure and low pressure bank. The 2200 cascade consists of 44 cylinders and approximate gas capacity of the cascade is 440 – 450 kgs and 3000 cascade consists of 60 cylinders and approximate gas capacity of the cascade is 620-640 kgs. Thus depending upon the capacity of cascade and number of cylinders, the cost of the cascade varies accordingly. The cost of each cylinder in the cascade is Rs. 15,000 – 20,000. IGL is incurring an expenditure of Rs 4.18/ km for transporting a CNG cascade.

Gas allocation to IGL

Gas allocation to IGL is 0.48 MMSCMD and the present consumption is 0.05 MMSCMD. The natural gas requirement for 10,000 buses would be 1.00 MMSCMD, Ministry of Petroleum & Natural Gas has assured IGL that additional allocation of gas shall be made available to IGL as and when required.

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