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Circular Bioeconomy Avenues of Green Hydrogen Production in Sugar and Distillery Industry

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ABSTRACT

India's industrial sectors use approximately 6 million tonnes of hydrogen annually. By 2050, that amount is expected to increase to 28 million tonnes. India wants to produce 80% of its hydrogen from green sources by 2050 in order to cut carbon emissions. In addition to ethanol and bio-CNG, green hydrogen will eventually account for a sizeable portion of India's energy needs as a cleaner fuel. The sugar and allied industries have a lot of potential for producing green hydrogen. Sugar industry generates excess electricity after captive consumption and nowadays, surplus electricity is sold to the grid. Electricity tariffs are decreasing day by day. The sugar industry is searching for economically feasible alternatives, such as the use of this electricity to produce green hydrogen through water electrolysis. Bagasse which is a carbon-neutral energy source that can also be used to gasify hydrogen. The sugar industry uses anaerobic digestion to produce biogas from press mud cake and spent wash. Hydrogen can be produced from methane or biogas using steam methane reforming. Vasantdada Sugar Institute in Pune has a green hydrogen demonstration plant with a daily capacity of 2 kg of hydrogen, based on water electrolysis technology. The techno-economic analysis of a five-ton-per-day green hydrogen plant that uses water electrolysis appears to be technically feasible with a payback period of less than five years, based on data from a hydrogen demonstration plant.

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Introduction

Recently, severe climate changes occur across the world due to the combustion of fossil fuels, which causes global warming. Fossil fuel is getting depleted day by day, so alternative energy is required, which should be an environmentally friendly [1, 2]. Energy consumption is an important factor for any countries developments which is growing rapidly. India's dependence on fossil fuels for its energy needs has two major concerns i.e. a growing import bill and the carbon emission. India is importing crude oil and gas of approx.13.1 billion dollars [3]. The energy consumption in different sectors is shown in Figure 1. Industrial, transport and domestic sectors are the largest sectors contributing to the energy consumption at 35%, 32% and 25%, respectively.

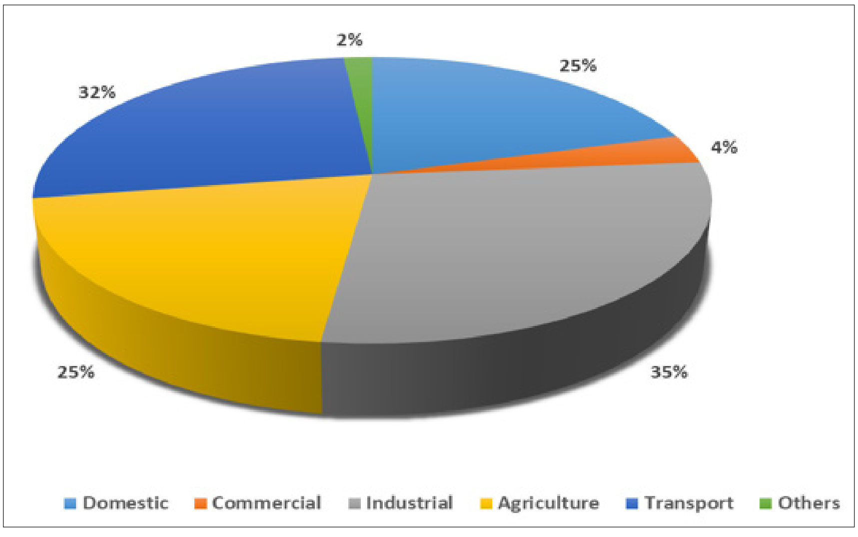

Figure 1: Energy Consumption in Different Sector (Source: Economist Intelligence, 2024)

India's energy supply is sourced from a variety of sources, including coal, oil, gas, hydrogen, renewable sources and nuclear (Figure 2). Significant efforts are being made to move towards energy conservation and new technologies associated with the use of environmentally friendly and renewable energy sources like hydrogen, bio-CNG, ethanol, methanol which will play an important role towards the sustainable growth of the country [4-6].

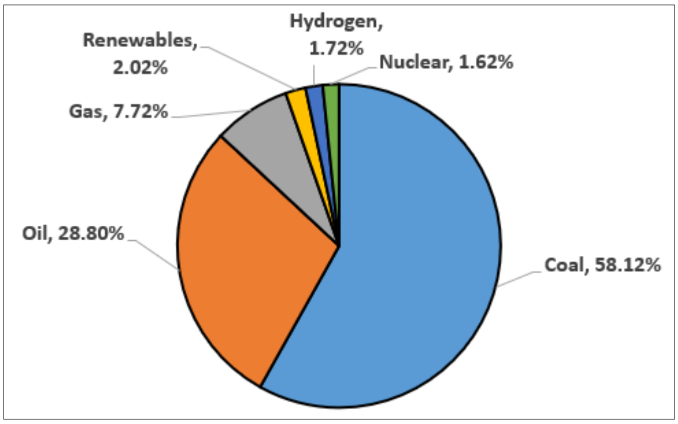

Figure 2: Source Wise Energy Supply in India (Source [7])

Hydrogen can be generated from diverse resources, which include fossil fuel resources such as coal, natural gas and renewable resources such as biomass, solar, wind, hydroelectric and geothermal energy. The source of energy and the production method used to make molecular hydrogen determines whether it is classified as grey hydrogen, blue hydrogen or green hydrogen. Table 1 shows typical classification of different types of hydrogen. Hydrogen is a colorless gas. The colour codes are only implications of the CO_2 emissions associated with that form of hydrogen.

Table 1: Hydrogen Variants

Hydrogen	Grey	Blue	Green
Feedstock	Natural gas or coal	Natural gas or coal	Water and electricity
Technology	Reforming; Gasification	Reforming with carbon capture; Gasification with carbon capture	Electrolysis
Byproducts	CO_2	CO_2 (Assumed captured and sequestered)	Oxygen
Environmental footprint	Medium or High	Low	Minimal

Worldwide, 70-75 million tonnes of total hydrogen is being produced out of which more than 70% generated from natural gas, around 27% generated from coal & less than 1% from electricity from solar/wind or renewable sources (green hydrogen). Globally, less than 1% of hydrogen of total hydrogen produced is green hydrogen. Now-a days, 38 million tonnes of hydrogen are being used for upgrading petroleum products in refinery and 31 million tonnes is being used as feedstock for ammonia production [8, 9]. In addition, there is a further 15-18 million tonnes of hydrogen produced as a by-product from other processes out of which 12-13 million tonnes of hydrogen is being used for manufacturing of methanol and 4-5 million tonnes of hydrogen is being used for manufacturing of steel.

India produces around 6 million tonnes of hydrogen which comes from grey hydrogen i.e. from methane reforming. Blue hydrogen which is basically a grey hydrogen with CO2 capture. However, India does not have any major facility to store and sequester CO_2. Therefore, blue hydrogen is not an option for India. Hence, Ministry of New Renewable Energy (MNRE) has emphasized directly to green hydrogen. Green hydrogen will be produced mostly by water electrolysis technology using electricity. India has set a non-biogenic greenhouse gas emission cap of 2 Kg carbon dioxide equivalent for 1 Kg of hydrogen produced through water treatment, electrolysis, gas purification and drying and compression of hydrogen. India consumes about 6 million tonnes of hydrogen every year for the production of ammonia and methanol in industrial sectors which can be increase to 28 million tonnes by 2050 (Figure 3). India targets green hydrogen production of 80% of total hydrogen production.

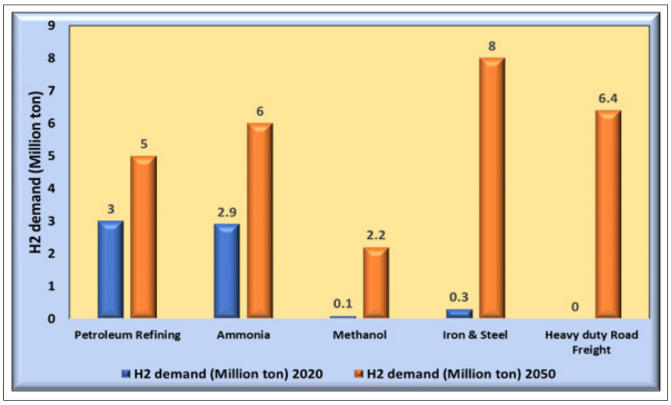

Figure 3: Hydrogen Demand in India [7]

Green hydrogen is better than petrol and diesel which is going to be the fuel of the future. Hydrogen based vehicles shows 3 times better mileage than diesel engines [10, 11]. Hydrogen is a cleaner fuel which upon combustion produces water. However, other fuels produce CO_2 on burning and contributes in pollution & global warming. Green hydrogen is considered the most suitable choice for the future energy market, both as energy storage media, energy vector and fuel for transportation, industry and other applications and net zero emissions to tame global warming and climate change [12, 13]. Today, the production of green hydrogen costs around USD 4-6/kg, and it is higher than ordinary hydrogen obtained from fossil fuels.

For sustainable future of sugar industry, biocircular economy approach needs to be adopted as shown in Figure 4 [14]. From sugar industry perspective, there are three options for green hydrogen production. Sugar industry is looking for economically viable alternative production like green hydrogen using water electrolysis through the use of excess electricity generated after captive consumption. Bagasse produced from sugar industry can also be used for hydrogen production through gasification. In another route, steam methane reforming can be used for production of hydrogen from methane/biogas produced through the use of bagasse, press mud cake and spent wash. This article focused on the opportunities for green hydrogen production using various technology options in sugar industry.

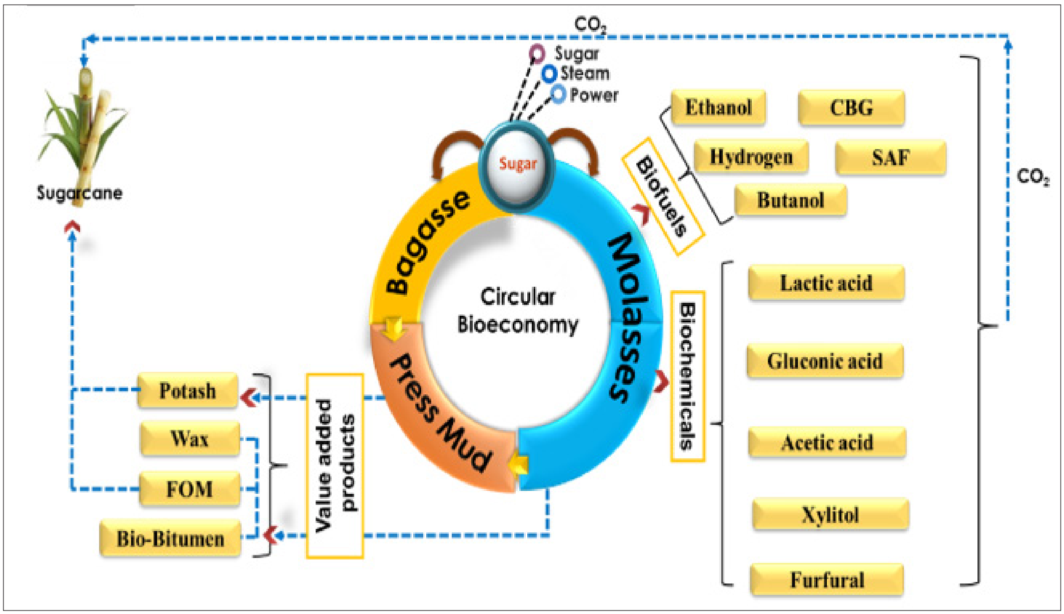

Figure 4: Biocircular Economy Approach for Sugar and Distillery Industry

Policy Initiatives by Government of India

Government of India announced a green hydrogen policy on 17th February 2022. On 4th January 2023, the Union Cabinet, Government of India approved the national green hydrogen mission with an outlay of Rs.19,744 crore from 2023-24 to 2029-30. The overarching objective of the mission is to make India a global hub for production, usage and export of green hydrogen and its derivatives. By 2030, India's green hydrogen production capacity is likely to reach 5 million tonnes per annum, contributing to reduction in dependence on import of fossil fuels. It is expected to reduce a cumulative Rs. 1 lakh crore worth of fossil fuel imports by 2030 and nearly 50 million tonnes per annum of CO2 emissions are expected to be prevented through production and use of green hydrogen.

National green hydrogen mission proposes a comprehensive Research and Development (R&D) programme to initiate innovation in various aspects of green hydrogen. Hydrogen technologies across the value chain are currently under development. Developed technologies such as electrolysers, fuel cells and carbon composite cylinders are not yet cost-competitive with another possible technologies. India's R&D roadmap for green hydrogen technology aims to address these challenges and develop innovative solutions based on new materials, technologies, and infrastructure. Presently, regulations and standards for the development and deployment of hydrogen at high pressure are not available in India. Government and industry should work together to formulate and implement regulations for certification and recertification before the large-scale deployment of hydrogen in India [15, 16].

India's national green hydrogen road map is shown in Figure 6. By 2020-25, India will focus on utilization of green hydrogen for enabling green ammonia for exports, refinery, ammonia for fertilizers and City Gas Distribution (CGD) blending. By 2025-30, green steel for exports and domestic, heavy-duty trucking will be focused for green hydrogen application. By 2040-50, green hydrogen will be utilized for seasonal storage applications, ships and airplanes.

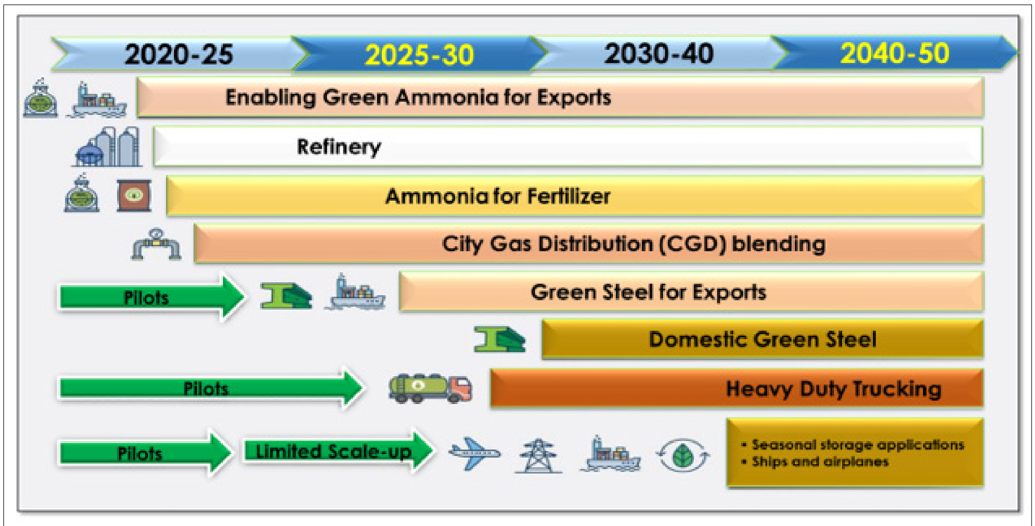

Figure 5: India National Green Hydrogen Road Map

Sugar Industry Perspective-Different Hydrogen Production Models

For the sugar mill perspective, the different possible models are discussed below.

Green Hydrogen Model 1: Biomass Gasification

Gasification is a process that converts organic or fossil-based carbonaceous materials at high temperatures (>700°C), without combustion, with a controlled amount of oxygen and/or steam into carbon monoxide, hydrogen, and carbon dioxide. The carbon monoxide reacts with water to form carbon dioxide and more hydrogen via a water-gas shift reaction. Adsorbers or special membranes can separate the hydrogen from this gas stream. Excess bagasse (carbon neutral energy source) is available with sugar industries. Bagasse can be used for hydrogen production using gasification technology (Figure 6).

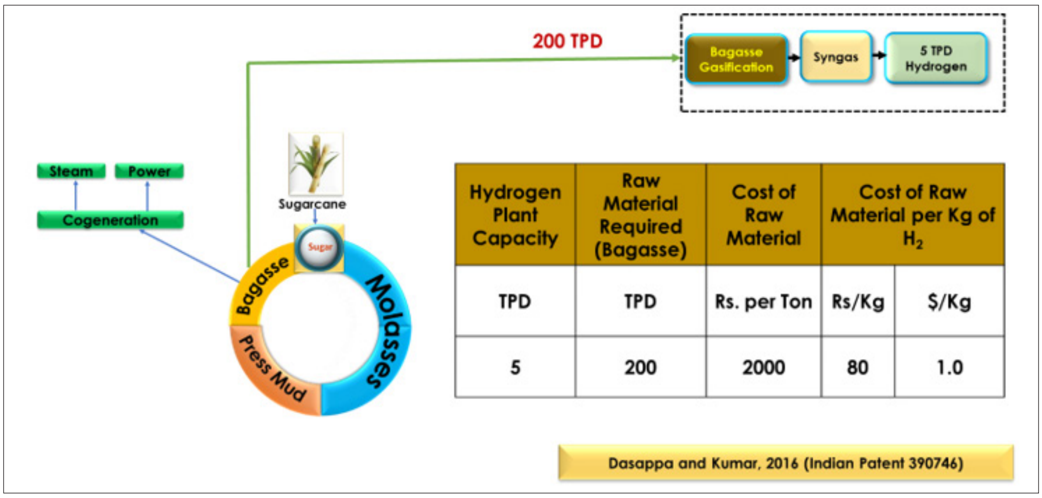

Figure 6: Schematic Diagram for Green Hydrogen Production (Model 1)

Green Hydrogen Model 2: Steam-Methane Reforming

Most hydrogen produced today is made via steam-methane reforming (using methane from fossil fuel source i.e. Natural gas), a mature production process in which high-temperature steam (700°C–1,000°C) is used to produce hydrogen from a methane source, such as natural gas. In steam-methane reforming, methane reacts with steam under 3–25 bar pressure in the presence of a catalyst to produce hydrogen, carbon monoxide, and a relatively small amount of carbon dioxide. Subsequently, using water-gas shift reaction, the carbon monoxide and steam are reacted in presence of a catalyst to produce carbon dioxide and hydrogen. In the sugar industry, spent wash and press mud cake is used for biomethane production through anaerobic digestion (AD). This methane can be used for the production of hydrogen through steam methane reforming process as shown in (Figure 7 & 8).

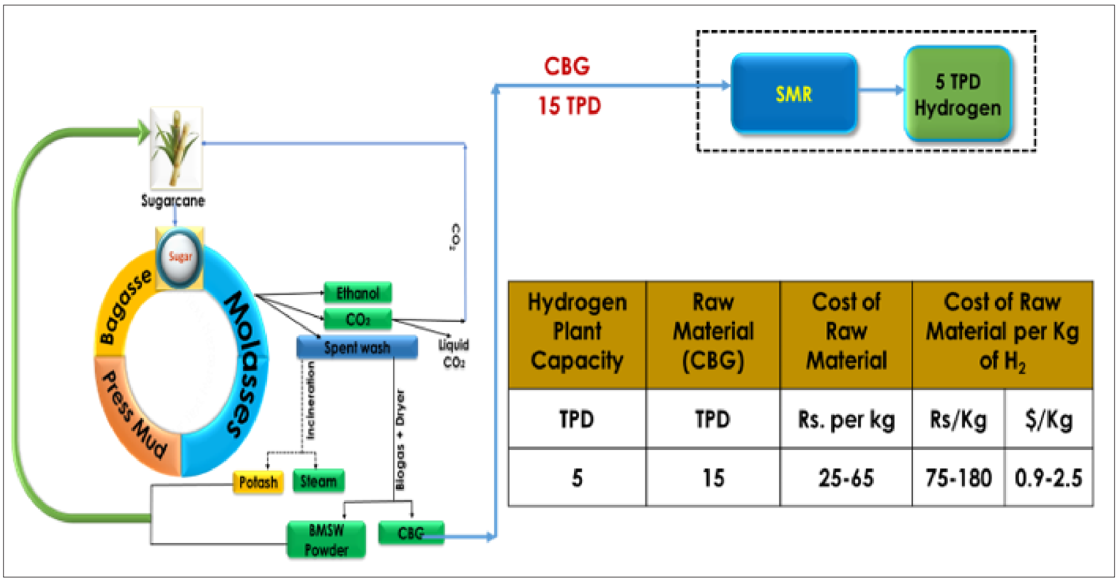

Figure 7: Schematic Diagram for Green Hydrogen Production (Model 2A)

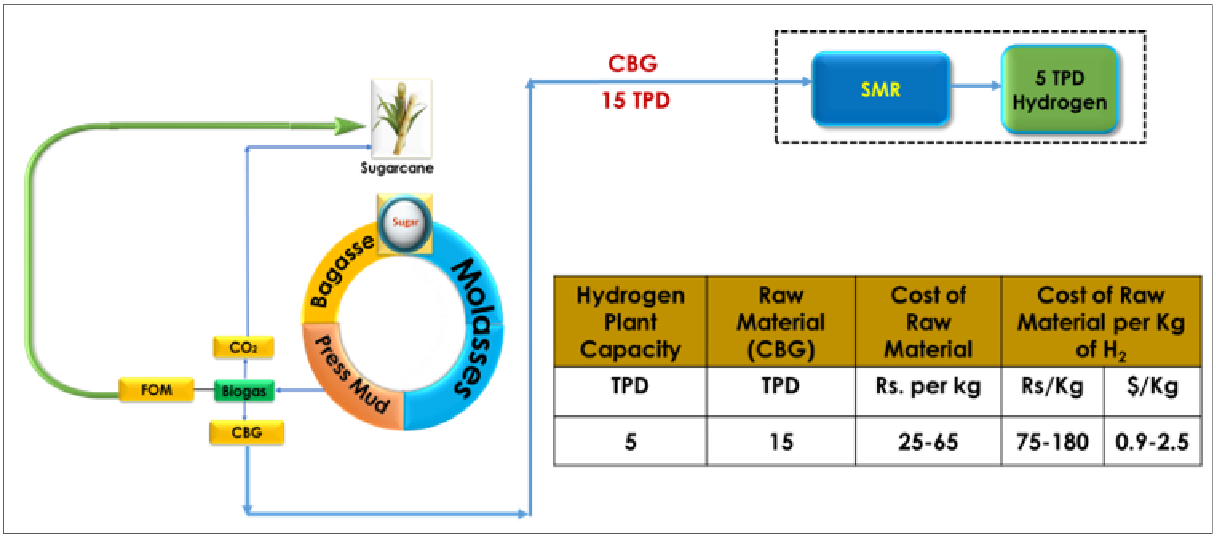

Figure 8: Schematic Diagram for Green Hydrogen Production (Model 2B)

Green Hydrogen Model 3: Water Electrolysis

In electrolysis, electricity is used to split water into hydrogen and oxygen using electrolyzer. The excess of power/electricity generated after captive consumption can be utilized for water electrolysis to produce green hydrogen (Figure 9).

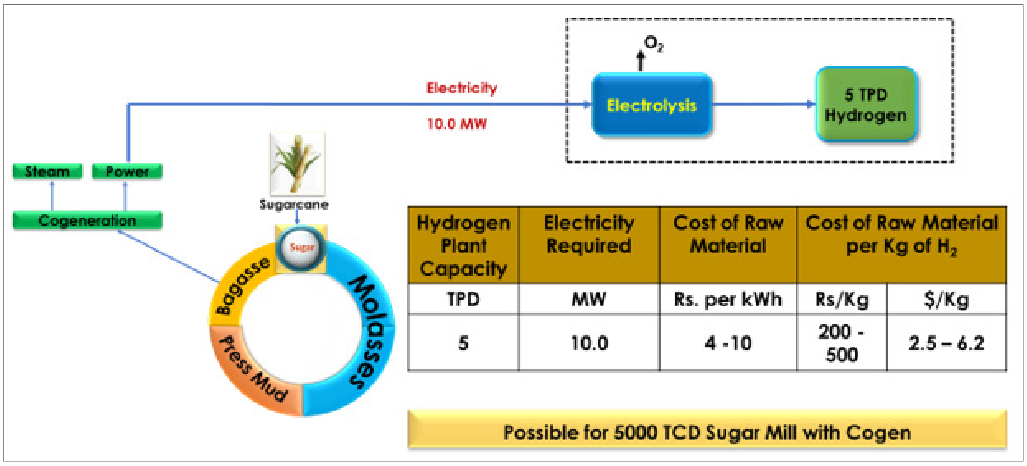

Figure 9: Schematic Diagram for Green Hydrogen Production (Model 3)

Conversion cost will vary from technology to technology (USD 1-1.5 per Kg of H2). Based on model 1, cost of raw material can be USD 1 per Kg of H2 for bagasse gasification. As per model 2A and 2B, cost of raw material can be USD 0.9-2.5 per Kg of H2 for biomethane based steam methane reforming. Further, based on model 3, cost of raw material can be USD 2.5-6.2 per Kg of H2 for water electrolysis using cogen electricity.

VSI Initiatives

It is advisable to evaluate techno-economics of above technologies by installing demo/pilot plants before going for commercial production. Hence, VSI has installed green hydrogen demo plant (Figure 10) using water electrolysis technology. In electrolysis, electricity is used to split water into hydrogen and oxygen. This reaction takes place in a unit called an electrolyzer. Further, the stored hydrogen was used to produce electricity through fuel cell. The installed system capacity is of 2 Kg green hydrogen per day. Green hydrogen production trials are in progress. On the basis of preliminary data, it was observed that around 58 kW power is required to produce 1 Kg of hydrogen.

Figure 10: Green Hydrogen Micro-Grid System Installed at VSI

Preliminary study of techno-economics for hydrogen production using electrolysis technology was performed (Table 2). For 5 TPD plant capacity, 10 MW capacity electrolyser will be required. If the plant will be operated for 150 days, Rs. 1850 Lakh will be cost per annum. Rs. 2850 Lakh revenue will be generated per annum. Thus, Rs. 1000 Lakh will be profit per annum and payback period will be 5 years.

Table 2: Techno-Economics of 5 TPD Green Hydrogen Plant

1.	**Hydrogen plant Capacity**	**5 TPD**	
	Required electrolyzer capacity	10 MW	
	Operating days	150	
	Capacity per annum	750 Ton	
	Capital cost	Rs. 5000 Lakh	USD 5.9 million
2.	**Rate of Hydrogen (purity > 99%)**	**Rs. 350 /Kg**	**USD 4.2**
	Green hydrogen subsidy	Rs. 30 /Kg	USD 0.4
	Revenue generated per day	Rs. 19 Lakh	USD 22,100
	Revenue generated per annum	Rs. 2850 Lakh	USD 3.3 million
3.	**Operational cost (Electricity, Water, Manpower)**		
	Electricity cost per day (@ Rs. 5/unit)	Rs. 12 Lakh	USD 14,000
	Cost per annum	Rs. 1800 Lakh	USD 2.1 million
	Man power and other cost per annum	Rs. 50 Lakh	USD 58,200
	Total cost per annum	Rs. 1850 Lakh	USD 2.2 million
4.	**Profit per annum**	Rs. 1000 Lakh	USD 1.2 million
5.	**Payback period**	5 Years	

Conclusion

Hydrogen production will play an important role in diversification of sugar industry product portfolio. Hydrogen can provide significant economic returns to the sugar industry and help to improve its financial position. From the sugar industries perspective, there are three options for production of green hydrogen. In future, detailed techno-economic analysis need to be carried out for all the options by installing demo plants for above mentioned technologies. The development of new technologies and gains in scale will allow for a reduction in costs.

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