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PRELIMINARY STUDY OF FEASIBILITY OF USING NUCLEAR HYDROGEN IN PUBLIC TRANSPORT IN THE METROPOLIS OF SÃO PAULO

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ABSTRACT

Hydrogen is a promising energy carrier, which potentially could replace the fossil fuels used in the transportation sector of the economy. Several methods have been proposed to produce hydrogen. These methods include steam methane reforming, electrolysis and thermo chemical cycles. Many different production concepts have been developed and studied. One of the leading methods for the production of hydrogen is nuclear energy. A large amount of energy is required to produce hydrogen. For many hydrogen production processes, input energy is needed in the form of either heat or electricity. Nuclear energy has the ability to provide either form with several advantages: Nuclear energy is abundant and does not depend on fossil fuels. It is environmentally friendly, avoidance of the production CO_2, with virtually no pollution emissions; production of hydrogen nears the final market, economics-of-scale that match the need for hydrogen, and availability of large resources of uranium fuel. Several types of reactors are being considered for hydrogen production. Hydrogen from nuclear energy may in fact become the enabling technology for a large-scale renewable nuclear economy. The purpose of this work is to analyze the process of production of hydrogen using nuclear energy, to check the economical, technological and environmental viability of use. To reach this objective will be analyzed existent technologies of nuclear hydrogen production and the impact of substitution fossil fuels, especially in public transport in a big Brazilian city like São Paulo.

1. INTRODUCTION

Hydrogen plays significant roles in the world economic today. Hydrogen technologies enabling policies are being developed in many countries for the building of a sustainable hydrogen energy economy.

Hydrogen is the most abundant element in the universe and the third most abundant on Earth [1] Hydrogen gas does not exist on the earth or in our atmosphere in significant quantities. Instead hydrogen gas reacts quickly with other elements to form more stable compounds. Hydrogen is not considered to be a source of energy because pure hydrogen is not as readily available. Hydrogen is considered to be an energy carrier. Like electricity, hydrogen is “manufactured”. Hydrogen is rare in nature and must be produced. Hydrogen production is one of the main areas of research throughout the world. Burning hydrogen with oxygen creates no pollution, the only byproduct of that combustion is water, but all phases of the cycle of hydrogen must be efficient. The input of a primary energy source is required. The primary energy source may include fossil energy (natural gas, petroleum and coal); renewable energy (solar, wind, and hydro electricity); biomass or biofuel sources and nuclear energy. Nuclear energy offers an abundant source of energy that is relatively cheap compared to fossil fuels [2] Nuclear energy is clean and environmentally friendly. There are no polluting emissions and a small amount of waste results.

2. CURRENT PRACTICE OF HYDROGEN PRODUCTION

Fossil fuels are used as the material sources of hydrogen produced in the world, including 48% from natural gas, 30% from oil, and 18% from coal. The remaining 4% comes from water. Biofuel and biomass is not significantly used now but interest in it is fast growing in the utilization of this renewable source.[2]

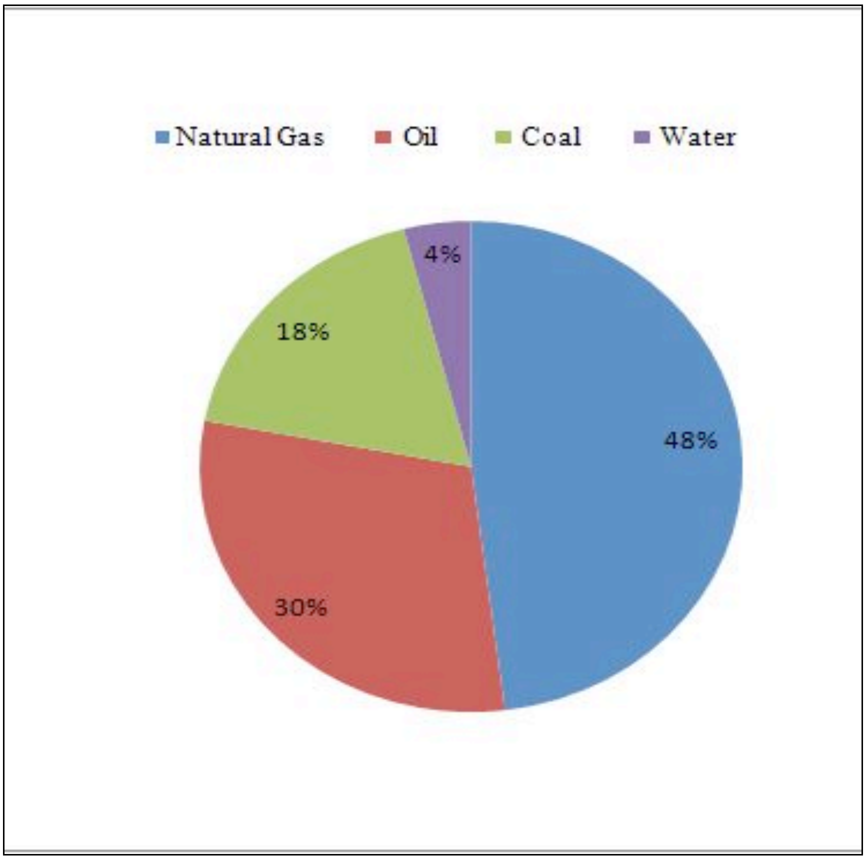

Figure 1. Material sources of hydrogen used in the world.

2.1. Methods for Production Hydrogen

There are several methods for producing hydrogen. All involve splitting compounds that contain hydrogen capturing. The methods are: electrolysis, steam reforming and thermolysis.

2.1.1. Electrolysis

Electrolysis splits water molecules into hydrogen and oxygen and it is the simplest method of hydrogen production, the method requires only a supply of water and electricity. The basic equipment is the electrolyser consisting of two electrodes separated by an electrolyte. Electrolysis of liquid water is the earliest hydrogen generation method and was commercialized as early as in 1890s. [1] Electrolysis is a proven technology and topic of recent studies for its potential application for nuclear hydrogen production. Electrolysis is environmentally friendly and ideal for remote locations.

2.1.2. Chemical reforming

Chemical reforming or steam reforming is a thermo chemical process used in industry that consists of reacting methane (or natural gas) and steam at high temperature. Steam reforming of various carbon and hydrocarbon sources leads to a product gas mixture rich in hydrogen. For example, steam reforming of methane (CH_4) at high temperatures (700-1100ºC) over a catalyst (nickel based) yields carbon monoxide and hydrogen. Steam reforming is the most efficient method of producing hydrogen today. In the United States, about 95% of the hydrogen is presently produced this way, and 45% in the world. A major disadvantage of the process to produce hydrogen is by production of CO_2. Capture and sequestration of CO_2 is feasible and would reduce production efficiency by about 1%. [3]

2.1.3. Thermolysis

Thermolysis is a thermal decomposition of pure water molecules into hydrogen and oxygen, requires the heating of water to 2000ºC for the decomposition just to begin and until 5000ºC for it to complete. Because all materials melt at these temperatures, construction for production plant becomes impractical. Incorporating cyclic chemical reactions can then be thermally decomposed to yield hydrogen and oxygen at far lower temperatures. This is called the thermochemical process. A thermochemical process consists of several chemical reactions. Studies of thermochemical processes for hydrogen production began in the 1960s [4] The Sulfur- Iodine (S-I) process is a thermo chemical water splitting cycles that consists of three chemical reaction witch sum to the dissociation of water.

The table 1 summarizes the comparison of the three processes for hydrogen production: electrolysis, steam reforming and thermolysis, the advantages, disadvantages of each one and describe feedstock, energy source and emissions of CO_2 of the current practice of hydrogen production.

Table 1. Comparison of three processes for hydrogen production

Production Routes	Electrolysis	Steam Reforming Chemical Reforming	Thermolysis Thermochemical process
Advantages	Simplest Method requiring	The most efficient method	High efficiency
Disadvantages	Requires electricity	Depend of fossil fuels	In early phase of development
Feedstock Current practice	Water and electricity	Various carbon and hydrocarbon sources Natural Gas	Water Sulfur and iodine
Energy Source Current Practice	Fossil and hydro electricity	Fossil fuels	Fossil fuels
Emissions Current Practice	CO_2 with fossil electricity	CO_2 capture and sequestration (CCS) is not practiced	CO_2

3. NUCLEAR HYDROGEN PRODUCTION

Nuclear power offers solution to hydrogen production processing with several advantages: increases in efficiency and dramatic reduction in pollution when compared with current practice of hydrogen production. Nuclear hydrogen satisfies each of the five criteria for future energy carrier: the new technology must be expandable; environmentally friendly; effective and improve the standard of living around the world; and economical. Using nuclear energy offers advantages in each phase of the lifecycle and it appears to be economically viable.[1]

Japan Atomic Energy Research Institute (JAERI) uses the HTTR (High Temperature Test Reactor) on steam reforming with a nuclear reactor. The high temperature helium cooled reactor provides the heat to the steam reforming system. [5]

The Sulfur-Iodine cycle was developed at General Atomics. Inc. (GA) with a high temperature nuclear reactor. GA and JAERI are the leaders in current research and development on the use of the sulfur-iodine (S-I) process. In their independent research, General Atomics and JAERI concluded that a High Temperature Gas Reactor is the best option for nuclear implementation of this process and has done preliminary cost estimates for the cycle [7]. The Sulfur-Iodine process originated and still develops with General Atomics of the United States. The advantages of thermo chemical processes are high efficiency, low production cost, environmentally friendly, independent of fossil fuels and attractive scaling characteristics for large scale nuclear hydrogen production applications.

Table 2 summarizes the comparison of the three processes for nuclear hydrogen. It includes cost estimates for production for new plants of each type, including the cost of nuclear reactor or electrical power plant.

The capital cost for construction of the Modular Helium Reactor has been used for the nuclear capital cost in all three options (including the cost of the turbine-generator in the electrolysis case). The cost is based on a capital recovery factor for a 10% interest rate and a 40 years lifetime with zero recovery value at the end of plant life. Operating costs are assumed to be a similar percentage of capital cost to that estimated for the S-I plant [6]

The production cost for electrolysis and the production cost for steam reforming are taken at the current minimum rates described in "Survey of the Economics of Hydrogen Technologies" [7]

Efficiency is defined to be the energy available from hydrogen produced (based on lower heating value) divided by the total of all energy input into the process (including energy used to produce electricity in the case of electrolysis).

Energy cost assumes 100% efficiency in conversion of hydrogen to energy.

Steam reforming is the cheapest hydrogen production method, even when implemented with a nuclear reactor. The S-I cycle is the second and electrolysis is the most expensive of the options. The cost of hydrogen from water electrolysis is significantly higher than any technology evaluated [2].

The heat applications, especially large-scale hydrogen production, represent new challenge for nuclear energy. The new mission would require a larger fleet of reactors than is presently used in the traditional mission of electricity production. The new challenges include research and commercial development for efficient, large-scale hydrogen production process suitable for use with the Generation IV nuclear reactors. Advanced nuclear systems must be developed to provide the suitable qualities of heat. The Generation IV International Forum is addressing the development of six advanced reactor system that not only meet the energy requirement for one or more processes but also improve safety a cost to encourage worldwide deployment.

Table 3 summarizes the nuclear Reactor Parameters for Hydrogen Production, describing the types of reactors, coolant, and the hydrogen production route.

Table 2. Comparison of the three processes for nuclear hydrogen

Production Routes	Electrolysis	Steam Reforming Chemical Reforming	Thermolysis Thermochemical Process
Advantages	-Proven technology -Ideal for remote locations -Independent of fossil fuels -Potential for electrical peak-shaving	-Proven technology -Near term nuclear capability -Lowest cost -Contributes to nuclear S-I development	-High efficiency -Low production cost
Disadvantages	Highest production cost	Must be in close proximity to the nuclear reactor	Must be in close proximity to the nuclear reactor
Feedstock Future Practice	Water (steam)	Biomass Fossil fuels	Water
Energy source Future Practice	Solar, wind, hydro or nuclear energy	Biomass, nuclear energy Fossil fuels nuclear energy	Nuclear energy, Solar energy
Emissions Future Practice	CO_2 free	CO_2 free CO_2 free by CCS	CO_2 free
Energy Cost	\$23/GJ to \$41/GJ	\$8/GJ	\$10/GJ
Efficience	25-45%	70%	50%
Preliminary Production Cost Estimate	\$2,70/kg to \$4,87/kg hydrogen	\$0,92/kg hydrogen	\$1,22/kg hydrogen

Table 3. Reactor Parameters for Hydrogen Production

Description	Coolant	Hydrogen Production Route	Electricity Generation Route
Light-water reactors PWR AP EPR BWR ABWR	Light water	Water electrolysis	Steam turbine
heavy water reactors: CANDU, ACR	Heavy water	Water electrolysis	Steam turbine
Supercritical water reactor S-LWR CANDU SCWR SF- LWR	Light water	Water electrolysis thermochemical	Steam turbine
Liquid metal fast reactors: SFR LFR	Sodium, lead, lead bismuth	Water electrolysis thermochemical	Steam turbine SCO_2 turbine
Molten salt reactors AHTR	Salts Li_2BE	Water electrolysis Thermochemical Steam electrolysis Chemical reforming	Steam turbine SCO_2 turbine
High temperature gas reactors HTGR VHTR	Helium	Water electrolysis Thermochemical Steam electrolysis Chemical reforming	Steam turbine Gas turbine
Gas-fast reactor GFR	Helium	Water electrolysis Thermochemical Steam electrolysis Chemical reforming	Steam turbine Gas turbine

4. HYDROGEN APPLICATIONS:

4.1 Ammonia Production

Ammonia (NH_3) is typically produced by catalyzed chemical reaction of hydrogen. Ammonia is used as fertilizers and it also contributes to the synthesis of pharmaceuticals the introduction of massive nuclear hydrogen would greatly increase agricultural productivity and sustainability by reducing the dependence on hydrocarbon resources. [2]

4.2 Petroleum Industry

Hydrogen is consumed in petroleum refining processes. Hydrogen is used to make petroleum products cleaner. Synfuel (Synthetic fuel is a liquid fuel obtained from coal, natural gas, oil shale, or biomass through numerous processes, of which Fischer-Tropsch and Bergius processes are often encountered, Hydrogen as a process reactant is required an can be obtained from steam reforming of natural gas. Use of nuclear hydrogen, heat and electricity could be cogenerated by Generation IV reactors would eliminate nearly all CO_2 emissions from the hydrogen production.

4.3 Industrial Applications

Hydrogen finds many uses in industrial applications including: food production, chemical manufacturing, metal work, aerospace programs, semiconductor manufacturing and power generation, where hydrogen is coolant for cooling large-scale high-speed turbine generators,

4.4 Fuel Cell

Hydrogen fuel and oxygen continuously feed into a fuel cell to generate direct electrical current and by products of water and heat. Hydrogen fuel cells are considered in various important economical applications, particularly for transportation an power generation. Fuel cells vehicles (FCVs) operate two times more efficiently than the most efficient gasoline cars including hybrid cars.

5. HYDROGEN IN PUBLIC TRANSPORT

The urban space is the result of the social work. The consequences of the urban works are the cities and mainly their transportations systems. The performance of the means of transport causes wide and deep impacts on the economic system, strategically influencing the progress.

The state of São Paulo is characterized by the predominance of public road transport as a major energy consumer. From the total energy consumed in transport, 83% was consumed by road transport, in 2005. [10] The means of road transport is one of the largest responsible for emissions of carbon dioxide. The purpose of this paper is introduce a study of the replacement of the road transport by rail using the hydrogen technologies as fuel cell.

In the State of São Paulo, the largest emitters of CO_2 belong to São Paulo metropolitan area.
The emissions of São Paulo city were 12.773,84 x 10^3 tons/year in 2010 [11].

The suggestion is to increase accessibility to all the location creating a homogeneous public transportation system on the metropolis of São Paulo, using an energetic technology that replaces the fossil fuels. This new technology would be the nuclear hydrogen, able to produce electric energy through the fuel cells.

Recently, China's first new energy fuel cell light rail train, developed by the China North Vehicle Yongji Electric Motor Corporation and the Southwest Jiasotong University was successfully launched. China's first fuel cell light locomotive adapts hydrogen as the energy for the fuel cells. It has provided a solution for the electrification of China's urban public transportation and the traffic congestion panic. It is also conductive to the promotion of China's new energy industry in a larger scope. [8]

In addition to a technology that replaces fossil fuels, there must be a policy of encouraging migration of individual transport to public transport.

The public transport distributed homogeneously in the metropolis of São Paulo using nuclear hydrogen in order to reduce carbon emissions and provide a better quality of life for the population has been studied in the PhD thesis of Patrícia Paladino, in progress.

6. CONCLUSIONS

Hydrogen is a promising energy carrier, which potentially could replace the fossil fuels used in the transportation sector. For hydrogen production processes, input energy is needed in the form of either heat or electricity. Nuclear energy has the ability to provide either form with several advantages: Nuclear energy is abundant and does not depend on fossil fuels. It is environmentally friendly, avoidance of the production CO_2, availability of large resources of uranium fuel.

Several types of reactors are being considered for hydrogen for hydrogen production, mainly the IV Generation Reactors.

This paper wants to call attention for the use of new technologies relating them to the urban transportation system of a big city as São Paulo. The urban space is the result of the social work and their study is inter-related to the various knowledge; the ability to cluster is only possible as consequences of the urban works. These consequences are the cities and mainly their transportations systems.

The suggestion is to increase accessibility to all the location creating a homogeneous public transportation system on the metropolis, using an energetic technology that replaces the fossil fuels. This new technology would be the nuclear hydrogen, able to produce electric energy through the fuel cells.

This new transportation has the function to improve the quality of the population's life reducing air pollution and travel time.

Those new ideas are suggestions for future work and need to be study carefully.

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