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Wind and solar hydrogen for the potential production of ammonia in the state of Ceará – Brazil

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ARTICLE INFO

Article history:
Received 4 May 2015
Received in revised form
5 June 2015
Accepted 10 June 2015
Available online 2 July 2015

Keywords:
Ammonia production
Hydrogen
Renewable energies
Wind
Solar
GIS

ABSTRACT

The main objective of this article is to analyze the feasibility of producing ammonia as main component for the synthesis of nitrogen fertilizers in the state of Ceará – Brazil. The potential for the ammonia production, via the Haber–Bosch process with electrolytic wind and solar photovoltaic hydrogen, is described with maps showing it per unit area in each municipal division of the state. Thus, by using high resolution solar radiation digital databases and average wind regimes databases (speed, Weibull factor, terrain roughness) available for Ceará, news maps of the potentials for solar and wind hydrogen are developed. Then a map of renewable hydrogen as the sum of both was created along with the corresponding potential for ammonia production with this renewable hydrogen. Land use and environmental externalities were considered as areas where energy development would be restricted.

Introduction

In face of the constant increase of the world population which by the year 1900 was about 1 billion, by the year 2000 it was about 6 billion and it is expected to be around 9 billion by the year 2050, the human society possibly will experiences shortage of fresh water, food, energy, and consequent problems related to climate changes [1]. Concerning food, the crucial challenge of the agriculture in the upcoming decades is to increase productivity in order to attend demand mainly of developing countries and Brazil is one of few countries in the

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http://dx.doi.org/10.1016/j.ijhydene.2015.06.044
0360-3199/

world which have conditions to face such demand, since United Nations previews Brazil producing 35% of the needed food in the world by the year 2019 [2]. Taking as reference the year 2011, if Brazil didn't have applied modern technologies in its agricultural sector it would be necessary almost 90 million hectares of supplementary land to attain the same production of that year. Nitrogen fertilizers for sure are one of the most important components responsible by the expressive increase in the average productivity of the Brazilian agriculture sector [3].

Being the basic component of nitrogen fertilizers, ammonia is an important and valuable chemical that is produced on massive scales throughout the world and used in other important fields of the human activity such as in refrigeration, textiles and metallurgical industries, to name a few. As projected by the InfoMine Research Group [4], the total world production of ammonia by the end of year 2013 reached 214 million tons. About 60% of the world production of ammonia is consumed by the industry of nitrogen fertilizers. The fertilizer industry consumes approximately 1.2% of the world's total energy demand on an annual basis and ammonia accounts for 87% of the total energy consumption of such industry [5]. By economic and environmental reasons, natural gas is the primary hydrocarbon feedstock used in ammonia synthesis although certain countries as for example China uses coal for almost all ammonia production. In the year 2008, 67% of the more than 130 million tons of ammonia produced in the world was fabricated by steam reforming natural gas, 27% by gasifying coal, and about 6% came from other fossil fuels such naphtha and heavy fuel oil and, in a tiny percentage from electrolysis of water [4]. Certainly the role of ammonia in the production of bioenergy feedstock and its potential use in solar and wind derived H_2 storage or as a liquid fuel will augment its criticality and importance in the global economy [1].

Although not being the focus of the present article where ammonia would be produced for the market of nitrogen fertilizers, it is also considered as an important fuel for the transportation sector. The role for ammonia and related chemicals such as hydrazine, ammonia borane, ammonia carbonate and urea as alternative fuels to hydrogen for vehicle motive power in the hydrogen economy is based in the facts that ammonia, in particular, has 1.3 times the heating value of liquid hydrogen, has an established world-wide infrastructure for its safe handling and distribution while its cost is roughly half of electrolytic liquid hydrogen [6,7]. For example, a medium size hydrogen car converted to ammonia becomes more effective per driving range cost, fuel tank compactness and improvement in the engine cooling system [8]. In recent years significant progress has been made on direct ammonia, hydrazine and urea fuel cells to generate electricity from these materials for transportation applications. The use of fuel cells fed by ammonia and related chemicals would have a higher efficiency and reduction of CO_2 emissions in the transportation sector [7].

Nearly all ammonia is produced using the Haber–Bosch (H–B) process, a reaction developed in 1909 by Fritz Haber and Carl Bosch to reduce nitrogen. The nitrogen feed for the H–B process is obtained separating nitrogen from air, usually by cryogenic methods. As stressed here before, the hydrogen of this process can come from steam reforming natural gas, gasifying coal or by cracking water into hydrogen and oxygen using electrolysis [9]. Hydrogen-rich synthesis gas is combined with nitrogen at high temperature and pressure to yield ammonia. Modern ammonia plants operate at around 350–550 °C and 100–250 atm while consuming about 30–38 MJ per kg of ammonia produced [10]. Although being a technology commercially proven, the Haber–Bosch process has some limitations as for example: it has not been used for small-scale plants. The economy of scale dictates current H–B facilities producing above 1500 ton NH_3 per day. This in turn has a direct impact on ammonia prices and their volatility [1]; natural gas and coal based ammonia production release 2.7 metric tons and 3.4 metric tons of the greenhouse gas carbon dioxide, respectively, for every metric ton of ammonia produced; natural gas, the main feedstock for ammonia, is expected to become more expensive over the next 20 years as demand outpaces supply; any significant disruption in natural gas supply can have devastating effects on the world population through decreased fertilizer production [11].

There are various alternatives in development for nitrogen fixation from the atmosphere via synthesis of ammonia such as catalytic formation near ambient temperature and pressure in the liquid phase, electrochemical synthesis and solar thermochemical synthesis of ammonia, and even biological ways of producing ammonia. However such proposals have not yet reached maturity [1,12]. As another alternative, it is possible to use renewable energy to feed the Haber–Bosch process. Electrical power produced by renewable sources such as wind, solar, hydroelectric, and ocean thermal energy conversion (OTEC) can be used to electrolyse hydrogen from water or brine solutions [13]. At present, electrolytic hydrogen is more expensive than hydrogen obtained from fossil hydrocarbons, but in the long run the progressive depletion of fossil fuels is destined to make renewable hydrogen more convenient and this route has the advantage that the existing Haber–Bosch plants could be kept and utilized without major modifications. Another eventual alternative is to use renewable electricity for the direct, high temperature electrolytic reaction of hydrogen and nitrogen. This method is called "solid state ammonia synthesis" or SSAS. There exist patents and known methods for this process although at present it is not used in industrial production [14].

Water electrolysis as a basis for ammonia production can be an interesting and competitive technology for countries with abundant availability of cheap electric power, or in cases where fertilizer production, e.g. for transport reasons, is desirable within an agricultural area not having fossil fuels available as raw materials [13]. Compared to steam reformed hydrocarbons, hydrogen produced by water electrolysis has high purity level. For this reason high-temperature "scrubbing" steps are not required and therefore schemes for renewably producing ammonia can be small compared to natural gas refineries [15]. Only 0.5% of the world's fertilizer is based on hydrogen produced by electrolysis of water. However, the steady increase in the price of natural gas and coal, their depletion, particularly natural gas, concerns about greenhouse gas emissions, results in an interest in the technology of water electrolysis, mainly because renewable energy is a rapidly expanding and consequently more