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Techno-economical assessment of coal and biomass gasification-based hydrogen production supply chain system

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ABSTRACT

Hydrogen is an energy carrier that represents a possible clean fuel of the future. This paper assesses the effect of biomass co-firing on gasification based hydrogen production supply chain, with carbon dioxide capture and storage, from technical, economical and environmental point of view. Several cases consisting of various feedstocks to the gasification reactor are investigated (coal only and coal in mixture with sawdust or wheat straw). Considered plant concepts generate between 330 and 460 MW hydrogen of 99.99% (vol.) purity.

First a performance analysis regarding the energy efficiency of the process, the syngas composition and the carbon dioxide capture rate is carried out. The simulations are made using chemical process simulation software Aspen Plus. Second, total capital investment and operating costs for the gasification plant are evaluated. Finally, using the results from Aspen Plus simulations and the cost estimations, a discrete event model is developed, to address hydrogen production supply chain analysis under demand variability, with Arena software. The implications of biomass co-firing on the system are evaluated in terms of: hydrogen amount sold and hydrogen amount stored (MW), hydrogen lost sales amount (MW), partial sales percent and gasification plant profit.

The results show that as the biomass quantity in the feedstock increases the hydrogen production rate decreases by 9–28% for sawdust, respectively by 7–23% for wheat straw. The energy efficiency of the process and the gasification plant profit also decrease, but the CO_2 emissions are lower for the cases of biomass co-firing.

Keywords: Hydrogen production; Biomass co-firing; Supply chain; Gasification; CO_2 capture; Entrained flow

1. Introduction

Currently, worldwide energy consumption is increasing rapidly leading to diminution of fossil fuels reserves (Asif and Muneer, 2007; Dagdougui, 2012). Also the energy production system based on fossil fuels exploitation is generating large amounts of carbon dioxide emissions, mainly responsible for climate change and global warming (Zanganeh and Shafeen, 2007). But, at the annual energy consumption, the solid fossil fuels have sustainable spare covering a longer period of time than the liquid and gaseous fuels and unlike the latter, the former are uniformly spread on Earth (British Petroleum, 2010; Kavalov and Peteves, 2007). Moreover, in the case of oil and natural gas supply, there is a close dependency on energetic imports from difficult geo-political regions on Earth. This energy dependence is thought to be rising considering the oil and gas supply in the North Sea have reached maximum levels of extraction, consequently these levels are going to decrease in the years to come (Cormos, 2008). In addition to the worldwide increasing need of oil for transportation and its continuously rising price, rigorous emission rules are creating the need for the diversification of the fuels used (Balat, 2008).

Hydrogen is regarded as a potential energy carrier of the future, vital for the sustainable development of the human society. Currently hydrogen is used in chemical and petro-chemical industry mainly in the ammonia or methanol synthesis process, hydrogenation, hydrocracking and hydrodesulphurization (Cormos, 2009). Hydrogen based economy is the long term view of many nations for a sustainable energy system (Saxe and Alvfors, 2007). The main goal

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of hydrogen economy is replacing the energy sources that are used at present (methane gas for generating heat and electric energy, liquid fuels for the transport sector) with hydrogen. Introducing hydrogen in the energy systems as an energy carrier complimentary to electricity represents an issue of importance due to the significant advantages it offers (IEA, 2003; IEA, 2007; Starr, 2009). One can mention the advantages of using hydrogen in the energy systems as an energy carrier complimentary to electricity are low greenhouse gases emission, increased energy delivery safety, and increased economic performance (Almansoori and Shah, 2012; Cormos, 2010a; Gnanapragasam et al., 2010).

Some economical, technical and environmental key aspects of hydrogen implementation in energy systems such as hydrogen cost, price of competing fuels, hydrogen purity and pressure, development of hydrogen technologies, greenhouse gas emission and regulations must be considered (Balat, 2008; Ball and Wietschel, 2009; Cormos, 2008;). Hydrogen price is highly influenced by the technology of producing it, by the cost of raw materials used and by the hydrogen delivery and storage options. Some of the most largely used industrial methods to obtain hydrogen are steam reforming, water electrolysis, polymeric membrane water electrolysis, photo-electrolysis, and photo-biological procedures (Folusho et al., 2009; Hollada et al., 2009; Navarro-Solis et al., 2010; Zeng and Zhang, 2010). Producing hydrogen through gasification of coal and biomass is a viable option for the future hydrogen economy, but carbon dioxide capture and storage are mandatory for the environment protection. Numerous publications for hydrogen production from coal and biomass, based on different gasification technologies are reported in literature. For instance, some papers analyze the co-gasification of coal and biomass in fixed bed reactors (Fermoso et al., 2010; Howaniec et al., 2011), some present the hydrogen production process through coal and biomass gasification based on entrained flow reactors (Cormos, 2012a) or fluidized bed reactors (Miccio et al., 2012). A review article regarding the co-gasification of coal and biomass is reported by Brar et al. (2012).

Hydrogen can be stored as liquid hydrogen, main advantage being its high density at low pressure, making it efficient for truck delivery (Aceves et al., 2006) or as compressed gas in high pressure vessels, a method preferred for fuel cell vehicle use, because of the affordable cost and the possibility of indefinite time storage (Ananthachar and Duffy, 2005; Balat, 2008).

There are several ways of hydrogen delivery: compressed gas truck delivery-fit for small hydrogen demand, cryogenic liquid truck delivery-for medium demand (between 400 and 4000 kg of liquid hydrogen) and delivery by pipeline, the latter being the cheapest option with the highest capacity of hydrogen delivery (Balat, 2008). High pressure is needed to ensure long distance transport from production sites to end-users with low energy consumption (pressure drop along pipes network). Ideally, the pressure should be equal to distribution network pressure 60–70 bar (Cormos, 2008). High purity hydrogen is essential to its use in transport sector (99.99% (vol.) purity is required for compatibility with PEM fuel cell) (Cormos, 2008).

As mentioned before, in literature there are numerous publications about hydrogen production from gasification of coal and biomass, but the research is mainly focused on analyzing the implication of co-firing at the production stage. Few papers reported in literature, like the work of Pérez-Fortes et al. (2011) addresses the techno-economic and environmental analysis of coal and biomass gasification based hydrogen production supply chain. This paper focuses on assessing the implications of biomass co-firing on gasification based hydrogen production supply chain, with carbon dioxide capture and storage, from the raw material supply, preparation and storage stages to the hydrogen production stage, from which hydrogen is delivered to consumers by pipeline transportation (Fig. 1).

2. Process description

2.1. *Gasification-based hydrogen production plant configuration*

Gasification is an old technology, being exploited for over 200 years (Higman and Van der Burgt, 2003). In the last decade the interest in gasification processes increased due to the worldwide efforts of introducing and developing hydrogen based economy.

Gasification technology presents a series of advantages in comparison to other hydrogen production processes (e.g. water electrolysis, steam reforming). Most important, through gasification the energy of a liquid or solid fuel (fossil fuels, biomass of different sorts or industrial wastes) is transformed into syngas with a useable heating value that can be processed to generate hydrogen as well as a large variety of chemical

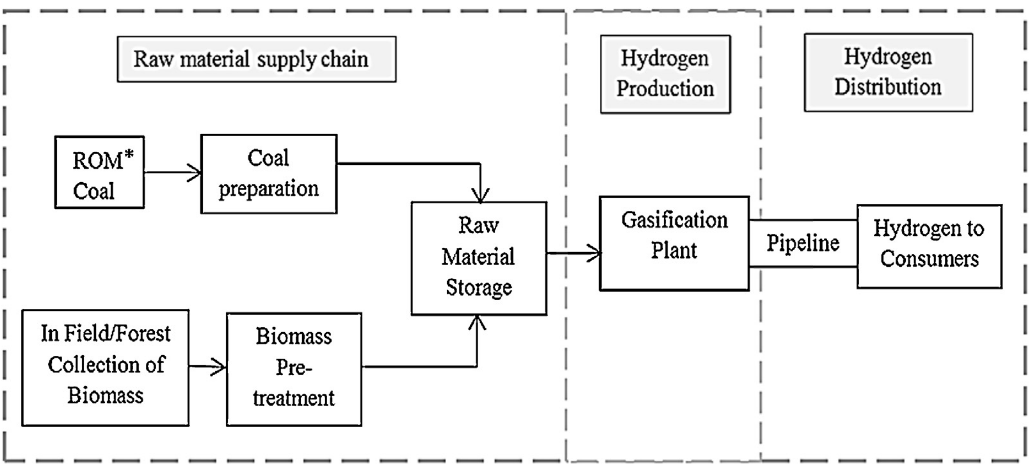

Fig. 1 – Hydrogen production supply chain.