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Development and assessment of a distribution network of hydro-methane, methanol, oxygen and carbon dioxide in Paraguay

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ABSTRACT

This paper summarizes key results of the analysis of different transport modes of hydro-methane, methanol, carbon dioxide and oxygen in Paraguay, Brazil and Argentina. Hydro-methane is produced in Paraguay and can be used to fuel natural gas vehicles, substituting gasoline and diesel which are at the moment imported from foreign countries. Methanol, also produced in Paraguay, is delivered to Brazil, which is one of the Countries with the highest demand in the region. Oxygen can be sold to Argentina for medical and industrial use. Carbon dioxide is delivered throughout Paraguay. The aim of this study is to determine the best transportation technology from an economic and strategic point of view, minimizing costs associated to products distribution. Several scenarios are investigated; each scenario is associated with different delivery modes. A model is developed to estimate both capital and variable costs for different transportation technologies (pipeline, trucks, ships) in order to choose the lowest-cost delivery mode for each product, depending on distances and flow rates. Four different analysis are performed for each scenario, varying the number of vehicles which must be fueled by hydro-methane and considering its influence on the results. The methodology presented here has a general value, thus it can be easily employed for the economic analysis of different fuels and distribution networks, also placed in different scenarios.

1. Introduction

Hydrogen has the potential to provide clean, secure and affordable services, acting as an energy carrier for a large range of applications [1]. However, several barriers still stand against widespread utilization of this technology. H_2 (hydrogen) still presents non-negligible management problems related to its transportation and final use, since fuel cells or H_2-ICE cars do not seem economical for short to mid-term applications [2]. An alternative is represented by hydro-methane production, mixing H_2 produced by water electrolysis with CO_2 in a chemical reactor [3], according to Sabatier reaction [4]:

$$4H_2 + CO_2 \leftrightarrow CH_4 + 2H_2O \quad (1)$$

Experimental tests carried out recently [4,5] have shown that not all the reacting H_2 and CO_2 are converted into methane, therefore the gas obtained can be classified as hydro-methane. Hydro-methane is a mixture of hydrogen and methane (H_2 from 5% to 30% in volume terms) that can be transported through methane infrastructures and employed in natural gas vehicles, as reported in [6]. The presence of hydrogen in the mixture allows for a more complete combustion, increasing efficiency and reducing HC and CO_2: results reported in [6,7] show reductions of 15% in terms of fuel input, 20% in terms of CO_2 emissions and 17% in terms of HC emissions for hydrogen-methane blends (with H_2 content of 20%) compared to Natural Gas vehicles. In this context, the mixture of hydrogen and methane could be a transitional step in terms of bringing hydrogen into transportation infrastructure [8].

For Paraguay this solution is very interesting for several reasons: the country has a large amount of electricity available for H_2 production, but no fossil fuel reserves, causing 100% of the latter to be imported.

The possibility of producing electrolytic hydrogen from hydroelectricity generated in the 14 GW Itaipu plant has been investigated in several works [9–11], in [9] have been shown the great potential of the energy wasted in ITAIPU dam that can be utilized for electrolytic hydrogen production and the country can obtain benefits. In this study the production of hydro-methane is proposed as a means to increase the electricity usage in Paraguay, where hydroelectricity achieves around 99.9% [12]; the maximum demand verified in 2012 was 2.3 GW, and Itaipu's electricity participation ranges between 70% and 80% [12]. Carbon dioxide needed for Sabatier reaction is obtained from biomass oxygen blown gasification, employing O_2 co-produced in electrolysers.

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Nomenclature

Abbreviations

ASU	Asunción
CDE	Ciudad Del Este
ICE	Internal Combustion Engine
PEC	Purchased Equipment Cost
PTI	Parque Tecnológico Itaipu
SNG	Synthetic Natural Gas
TCI	Total Capital Investment
TPG	Thermochemical Power Group

Symbols

C	cost (€)
c	specific cost (€/kg)
M	mass flow (kg/h)

Subscripts

f	fuel
fix	fixed
var	variable

The syngas obtained (after cleaning and Water Gas Shift treatments) is made of H_2, CO and CO_2; CO_2 is separated in a Selexol unit while H_2 and CO are used to produce methanol, as follows:

$$2H_2 + CO \leftrightarrow CH_3OH \quad (2)$$

The process for methanol synthesis by biomass gasification is well known, as reported in [13]. The simplified scheme for hydro-methane and CH_3OH production described above is reported in Fig. 1.

To investigate the best solution, the advantages and disadvantages associated with the distribution logistics for the main product (hydro-methane) and by-products should be evaluated. In Paraguay the transportation is mostly carried out by trucks and ships, since no rail network exists. Several rivers and tributaries cross the Paraguayan territory, encouraging the development of shipping sector and ports. The most important rivers are the Paraguay and Parana, both are almost entirely navigable year round. The road network links the principal cities with the capital.

In the present work the economic analysis is carried out for different scenarios in order to identify optimal solutions for different configurations and sizes. The analysis is performed using a software known as WEPoMP (Web-based Economic Poly-generative Modular Program), developed at University of Genoa. Two main urban areas of Paraguay are selected as scenarios; the map of the country is shown in Fig. 2.

2. Proposed scenarios

Since Paraguay is the setting chosen for this study, it is advisable to summarize the main information related to this Country. Paraguay consists of seventeen departments and one capital district of Asuncion surrounded by the Central department. In 2012 the estimated population was around 6.7 million [14]. For the purposes of this paper Asuncion (referred to as ASU) and Ciudad del Este (referred to as CDE) are taken into account. Table 1 shows the main data for these locations [14,15].

CDE is located in the Alto Paraná department, strategically positioned at the border between Paraguay, Brazil and Argentina. The metropolitan area, which includes the four cities of Ciudad del Este, Hernandarias, Presidente Franco and Minga Guazu, is the second largest metropolitan area in Paraguay [15]. Asuncion, which is an autonomous capital district not part of any department, is the most populous city in the country; the metropolitan area known as Gran Asuncion includes the surrounding cities which are part of Central department.

In regards to mobility, Paraguay has 1,063,262 registered vehicles, according to [16]: around 49% are passenger cars. Roughly 75% of these are concentrated in three locations: Asuncion, Central and Alto Paraná. Table 2 shows the data used for estimations.

According to [17] 1089.8 ktoe of Diesel oil and 368.8 ktoe of gasoline are consumed in Paraguay, these products are 100% imported. The ratio between consumption of the two fuels is around 3–1; this value taken into account for emissions calculation. For

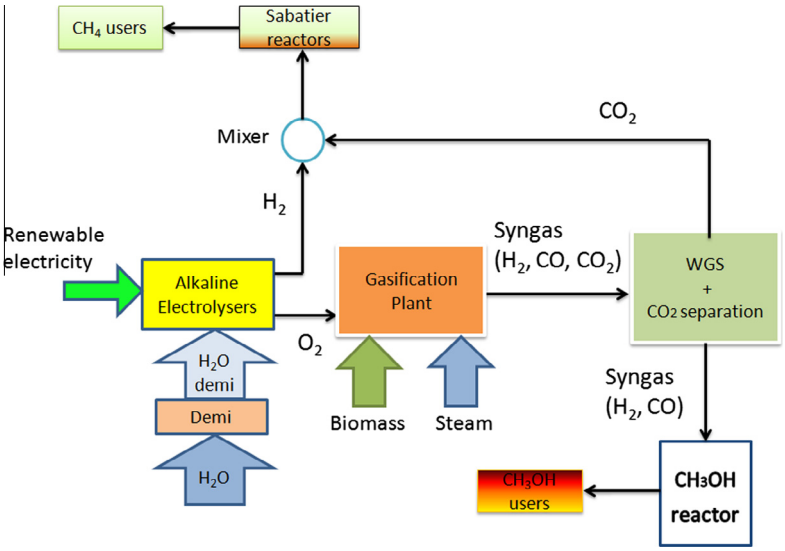

Fig. 1. Hydro-methane and methanol production plant.