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South Patagonia: Wind/hydrogen/coal system with reduced CO_2 emissions

G. Spazzafumo*

University of Cassino, DIMSAT, Via G. Di Biasio 43, I-03043 Cassino, Italy

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ABSTRACT

Wind is a significant renewable energy source in Patagonia, which could generate a very large amount of electrical energy. However, it is not possible to put such a large amount of energy on to the grid due to instability issues. Electrolysis could facilitate the storage of such energy in the form of hydrogen, which could be used for peak power production or for vehicles. However, hydrogen storage and distribution are still very expensive.

On the other hand, South Patagonia has reserves of coal whose exploitation is not easy. One solution could be underground coal gasification. Unfortunately using coal results in high emissions of carbon dioxide.

Hydrogen from wind energy could be the solution to convert coal to methane and to eventually generate electrical power. In this way, a large amount of renewable energy could be introduced to the energy system with a reduction in the emissions of carbon dioxide.

1. Introduction

One of the main issues currently facing the energy sector is the reduction of carbon dioxide emissions. Moreover we have to face the next peak of production of oil and natural gas, which are the fossil fuels most utilised in transport and residential applications. Among the most utilised primary energy sources, coal seems to be unique in that it is far from the peak of production and is less concentrated geographically. As renewable energy sources cannot satisfy the whole energy demand in the short/medium period, we should consider using coal.

Unfortunately, coal has the highest C/H ratio and results in the highest carbon dioxide specific emissions.

At present, almost all renewable energy sources generate electric power but at insufficient levels to meet the demand. In order to further exploit the potential of such sources a storage system is required and hydrogen is considered to be the best solution. Unfortunately, transport and residential applications require that hydrogen be distributed and building a suitable infrastructure is rather expensive.

One of the technologies that is proposed for the production of substitute natural gas (SNG) is carbon dioxide capture from the atmosphere and subsequent methanation using hydrogen [1]. However, the scrubbing of atmospheric carbon dioxide is an open challenge for which many theoretical ideas have been developed but without any current practical application.

Abbreviations: CC, combined cycle; CNG, compressed natural gas; E, electrolyser; GCS, gas cleaning system; GHG, greenhouse gas; HCNG, hydrogen & compressed natural gas (blend); NMHC, nonmethane hydrocarbons; M, methanator; SNG, substitute of natural gas; SR, Sabatier reactor; UCG, underground coal gasifier; UCHG, underground coal hydro-gasifier; WS, water separator.

* Tel.: +39 0585 52761.
E-mail address: spazzafumo@unicas.it.

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Argentina is using coal to generate electric power and has significant coal reserves but which are not easy to extract. It also has a great wind potential, which could be used to produce hydrogen. Finally, it has a large infrastructure to distribute natural gas: more than 28,000 km of pipeline to distribute more than 40 Gm3/y of natural gas [2]. Such an infrastructure could be used to distribute SNG. Considering all these factors it seems possible to reduce the amount of imported fossil fuels and to reduce carbon dioxide emissions.

2. Coal resources and underground coal gasification

Coal production in Argentina was mainly located in Rio Turbio (Santa Cruz) and mainly devoted to electrical power production in a plant located in San Nicolas (Buenos Aires) [3] but ceased in 2003. The coal from Rio Turbio is sub-bituminous and the reserves are estimated to be 580 million tons.

However, there are some important seams of lignite in Santa Cruz. The two main seams are in Rio Coyle (5000 million tons) and in Rio Santa Cruz (2350 million tons) and they account for more than twice the known reserves of oil and natural gas in Argentina.

In order to exploit such resources, Shalamuck [4] proposed the technology of underground coal gasification (UCG), which is an in-situ gasification process carried out in the coal seams by injecting oxidants and recovering the produced syngas at the surface. Experimental tests have been conducted in several countries and around 50 years ago, five industrial-scale UCG plants were operating in the former Soviet Union. One of these (Yerostigaz), located in Angren (Uzbekistan) has been operating since 1961 and continues to produces 1 million cubic metres of syngas per day [5]. Several researchers are working on UCG to analyse and improve the process with particular emphasis on obtaining hydrogen as the final fuel [6–9].

UCG facilitates the exploitation of coal resources not economically recoverable by other technologies. This would seem to be the case for the Santa Cruz lignite seams where there are environmental and cost benefits in eliminating mining activity and solid waste and by replacing coal transport with gas piping.

In general, a UCG plant has three wells:

- an ignition well, in which a gaseous fuel is injected to start the combustion process;
- an injection well, in which the oxidants (air or oxygen and steam) are supplied to the seam;
- and a production well, from which the generated syngas is extracted.

The syngas produced could replace natural gas in combined cycle power plants, allowing higher conversion efficiency compared with the direct use of coal.

The regulation of the oxidant flow permits a controlled combustion at temperatures ranging from 700 to 1500 °C. A pyrolysis process uses the heat generated by the combustion to decompose the coal. The following gasification reactions produce a syngas that is mainly composed of carbon monoxide, hydrogen, methane, carbon dioxide and steam. Depending on the quality of coal, the reactions also produce small quantities of contaminants, such as nitrogen oxide and hydrogen sulphide. With reference to its weight, lignite contains 60–70% carbon, 5–6% hydrogen, 20–30% oxygen, 0.5–1.5% nitrogen and 1–4% sulphur. This means that lignite has an average empirical formula that is: C_4H_4O with traces of nitrogen and sulphur.

However, the syngas composition is highly affected by the oxidant. Using air, the syngas is greatly diluted due to the presence of large amounts of nitrogen. Therefore, it could be burned directly on-site to produce electrical power. Using oxygen, the heating value is higher because the unique significant diluent is carbon dioxide. Finally, adding steam results in a higher hydrogen concentration.

Therefore, UCG allows efficient exploitation of coal resources with several advantages but cannot significantly reduce the greenhouse gas (GHG) emissions connected with the utilisation of coal. The CO_2 produced could be partially re-injected into the seams where the coal was processed by combining UCG with carbon capture and storage technology (CCS).

3. Wind resources and electrolysis

In most of the country but especially in Patagonia, wind is suitable for power generation. Patagonia can be considered as the region lying between 38° and 56° south. In the zone between 40° and 50°, the winds are permanently directed in the sector from W-SW to SW. The average wind speed is in the range 9–12 m/s for a large part of the region and the capacity factor is maybe the highest in the world (e.g., 42% in Comodoro Rivadavia and 47% in Pico Truncado) [10]. Such conditions are typical of some islands or off-shore plants and nowhere else on the mainland are there similar conditions.

Obviously, such a potential for power production is too large to be fully delivered to the electric grid because it would give instability to the grid itself. Therefore, the production of hydrogen was proposed as an energy storage system [11]. Actually, South Patagonia has important resources in terms of wind, water and land (Table 1) and could become one of the main hydrogen producing areas of the world [12]. For such

Table 1 – Chubut and Santa Cruz: wind, water, land and population.

	Wind speed [m/s]	Capacity factor [%]	Rivers' average flow [m^3/day]	Area km^2	Density Inhab./km^2
Chubut	6–10	42	7,150,000	225,000	1.8
Santa Cruz	7 to >10	47	66,700,000	244,000	0.8