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A technical and environmental comparison between hydrogen and some fossil fuels

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ABSTRACT

The exploitation of some fossil fuels such as oil, intended as gasoline or diesel fuel, natural gas and coal, currently satisfy the majority of the growing world energy demand, but they are destined to run out relatively quickly. Beyond this point, their combustion products are the main cause of some global problems such as the greenhouse effect, the hole in the ozone layer, acid rains and generalized environment pollution, so their impact is extremely harmful.

Therefore, it is clear that a solution to the energy problem can be obtained only through the use of renewable sources and by means of the exploitation of new low-polluting fuels.

In this scenario an important role might be played by hydrogen, which is able to define a new energy system that is more sustainable and cleaner than current systems.

For the comparison of the different fuels investigated in this paper, a methodology, which defines appropriate technical and environmental quality indexes, has been developed. These indexes are connected to the pollution produced by combustion reactions and to their intrinsic characteristics of flammability and expansiveness linked to the use of the considered fuels. An appropriate combination of these indexes, in the specific sector of utilization, allows to evaluate a global environmental index for the investigated fuels, highlighting that hydrogen reaches the highest score. In the final part of the paper, a new hydrogen energy economy that would lead to solving the serious environmental problems that damages all the ecosystems of the planet earth, is presented.

1. Introduction

In recent years, the problem of air pollution has reached limits of considerable dangerousness both human health and for the environment that surrounds them [1,2]. This situation is the direct consequence of the continuous and copious reversal in the atmosphere of combustion products provided by energy systems, which employ, especially, fossil fuels.

Unfortunately, these emission levels have been increasing proportionately according to industrial progress, pursued by different nations for a long time, together the relative population growth.

Three possible scenario trends of industrial development with a well-defined model of population growth are shown in Fig. 1. The latter concomitant factors are the main reasons for the energy requirement growth, and they lead to emissions of large quantities of pollutants, such as SO_x, N_xO_y, particulate, carbon monoxide and carbon dioxide, which create serious environmental problems and liveability.

In this context, hydrogen has a role of primary importance to solve these serious environmental problems [3–7]. If hydrogen is introduced into the actual energy system based on the exploitation of fossil fuels, it would allow for a reduction of the local environmental impact of fuels, whilst also reducing the global impact. If hydrogen production is carried out starting from renewable sources, the world impact will also be solved. However, molecular hydrogen is not available in nature, so it must be produced using energy.

Hydrogen can be stored both in liquid or gas form, and it could later be converted into thermal energy by its combustion. For this reason, hydrogen is an energy carrier. The advantages of using hydrogen in energy systems are numerous; the main reason is the ability to produce electricity and heat using fuel cells [11–13]. These devices are characterized by high efficiency and no pollutant emissions (water vapour). In this sense, it can be defined as a clean energy carrier.

Currently, despite different ways of producing hydrogen in a molecular form, it is more expensive than fossil fuels, but only if the costs concerning social and environmental impacts are excluded [14–16].

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After a review of the several methods and strategies for hydrogen production, hypothesizing the most frequent uses in the various areas of intervention, this paper proposes suitable indicators to quantify the real advantages of hydrogen as new fuels with regard to the technical and environmental aspects.

A comparison between conventional energy systems, which exploit fossil fuels, and a sustainable hydrogen energy system is proposed defining appropriate technical and ecological quality indexes.

For this purpose, in the first part of the paper hypothesizing standard combustion, the effects concerning pollution, flammability and expansion properties of hydrogen and other fossil fuels (coal, methane and gasoline) have been investigated. In the second part of the paper, a new economic scenario based on hydrogen systems to solve environmental problems such as the greenhouse effect, acid rain, the hole in the ozone layer and widespread pollution, is evaluated.

1.1. Environmental damage and security in production of heat

The production of heat and electricity through the use of traditional fossil fuels (methane, coal and oil) and with an alternative source as hydrogen, gives rise to two types of problems.

The first, as already mentioned in the introduction, is associated with environmental damage, resulting in the emission of large amounts of pollutants during their combustion.

The second problem concerns the security of the thermal process of energy production by exploitation of the fuels.

Regarding environmental damage, today the growth of energy requirement is the main reason concerning the emission of large amounts of pollutants, such as SO_x, N_xO_y, particulate, carbon monoxide, carbon dioxide and water, which cause serious environmental and living condition problems [17–19].

To provide an idea of the effects on air pollution associated with the continuous augment of the use of fossil fuel, the production of CO_2 and other mentioned chemical pollutants in more industrialized countries is reported in Table 1 [20].

Table 1
Comparison between the main pollution emissions in the more industrialized countries.

State	Pollutants products from combustion (in 10^3 ton)				
	Sulphur dioxide SO_2	Nitrogen oxides N_xO_y	Suspended particles	Carbon oxide CO	Carbon dioxide CO_2
USA	23,200	20,300	8300	77,400	4,166,000
Japan	1314	1435	–	–	831,000
German	3200	3100	725	8650	666,000
UK	4670	1812	442	8891	517,000
France	3460	1847	278	5200	404,000
Italy	3205	1506	433	5487	322,000
Spain	3756	792	1521	3780	198,000
Holland	450	525	150	1450	130,000
Belgium	856	317	267	839	107,000

In this context, it is important to focus on the problem of the increase in CO_2, which has grown since 1890–2009 from about zero to 22×10^{12} kg/year. In other terms, CO_2 has grown from zero to about 360 ppm, corresponding to a level of 800 mg/Nm^3 [21].

Nowadays, this concentration can appear to be not very high considering a limit of 9000 mg/m^3 in closed environments imposed by actual standards; generally this limit is never reachable hypothesizing the possibility of providing the indoor environment with ventilation systems for renewal needs.

Contrarily, the concentration of CO_2 and other gases contributes for 55% of the so-called greenhouse effect (see Fig. 2), the main reason for the earth's average temperature increment, with consequent melting of the great glaciers which could be responsible for serious problems in coastal areas around the world.

The trend in global temperature due to the increase of CO_2 in the atmosphere, adjusted considering the rate absorbed by the oceans and the mainland, is shown in Fig. 3.

Recent studies have made it possible to hypothesize how in the next 200–500 years, an augment of the sea level up to 3–4 m may be possible, while there will be an increment of 0.2–1.5 ml only in the next century [24].

Fig. 4 shows that the majority of CO_2 originates from the combustion of coal, oil and methane and, to a lesser extent, from deforestation; other productive activities, such as cement factories, are responsible for another small part of CO_2.

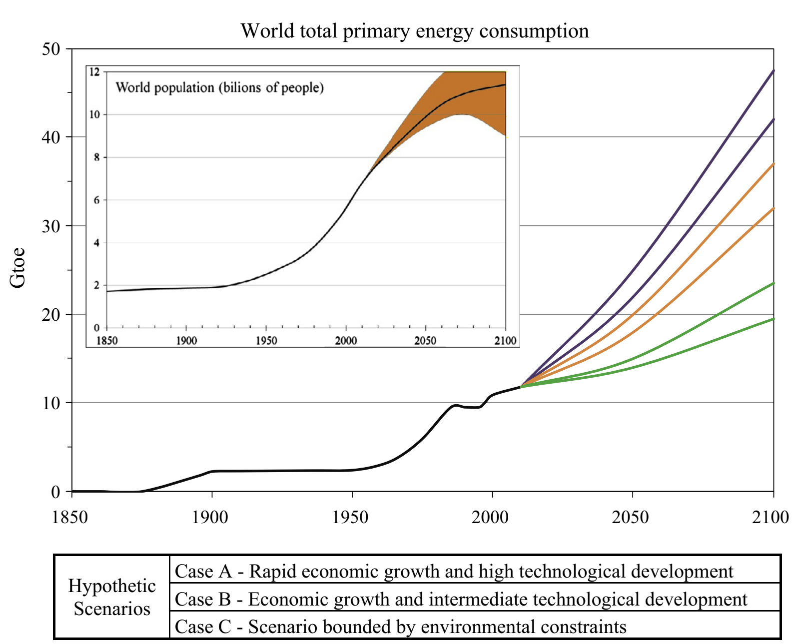

Fig. 1. Trend of primary energy requirements and world population growth until 2100 according to three different scenarios [8–10].