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Thermodynamic and Irreversibility Analysis of the Use of Hydrogen for the Energy Conversion of Fossil Fuel in Power plants

Nima Norouzi*

Abstract – This work seeks to investigate the possibilities of using hydrogen as a fuel in medium-large power generation plants. Possible strategies for converting fossil sources, particularly coal and natural gas, into electricity, using hydrogen-powered cycles, are examined, trying to quantify the energy efficiencies of thermodynamic cycles and the entire conversion process. It is observed how, by analyzing the entire conversion process from a thermodynamic point of view and taking as a reference possible thermodynamic cycles proposed in the literature (open H2-air and closed H2-O2 cycles), the overall efficiencies of the conversion process, from the source fossil to electricity passing through hydrogen as an energy vector, are overall lower than those obtainable through conventional systems used today, even assuming the use of advanced technologies (turbines with operating temperatures above 1500 ° C) not yet available on the market. In particular, the overall efficiencies of the conversion process are less than 40% in the case of coal and 50% in the case of natural gas. The road to using hydrogen, therefore, although interesting, is still long and difficult.

Keywords: Hydrogen, Clean energy, Cogeneration, Exergy analysis, Power and hydrogen

1. Introduction

The idea of using hydrogen as a fuel is historically traceable to Cavendish's experiences in the second half of the 18th century. However, on a scientific level, a strong impulse towards hydrogen in the energy sector came only after the first oil crisis. In 1974 in Miami, the first international hydrogen conference was organized (THEME: The Hydrogen Economy Miami Energy Conference) from which the International Association for Hydrogen Energy (IAHE) originated and what has been the main source for the last 30 years of debate on hydrogen and its energy uses, the International Journal of Hydrogen Energy [1]. In a very recent past [2], the illusion of a forthcoming "Hydrogen Economy" [3] has been re-proposed, an economy that, thanks to hydrogen, "clean fuel," finally becomes respectful of nature. That hydrogen can finally find the lasting and eco-compatible solution to the energy problem. This has given rise to a certain interest in the subject witnessed by the exponential growth of publications on the subject in the last two years.

Although the topic arouses considerable interest [5], the inconsistencies related to some overly optimistic views on hydrogen are evident as soon as the topic is investigated. Although hydrogen is a very abundant element in nature, it is not found free but must be "produced," isolating it from the elements with which it is bound. This is why it is considered not a "source" of energy but an "energy vector," a sort of container to store energy from another source. The essential aspect is that the production phase and storage and distribution require energy, and therefore the hydrogen chain has an efficiency far from the unit value. From a technological point of view, there are also problems related to transport and use.

Beyond the socio-economic aspects, the advantages of hydrogen development could emerge from some three aspects. First of all, for the storage of electricity, when this is available more than the capacity of use, which is not at all unlikely in times of liberalization of the electricity market. In this sense, hydrogen could perform a function similar to that of water in hydroelectric storage by pumping plants that use the excesses of electricity produced (mostly at night) to pump the water back into the basins and cope with the maximum loads, On the network. Hydrogen could also make it possible to obtain the leveling of plant loads, where there is an excess of electricity produced. Rather than assuming unlikely operations in off-project conditions,

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* **Corresponding Author:** Energy and Physics Department, Amirkabir University of Technology, 424 Hafez Ave., Tehran, Iran, nima1376@aut.ac.ir

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the plants could operate at maximum load, and the electricity not fed into the grid used to produce hydrogen to be used in other areas (for example, in transport).

It is also clear that hydrogen could contribute to a "cleaner" use of fossil fuels; if used directly as a fuel, it emits only water vapor and nitrogen oxides, polluting emissions to the production sites.

Leaving aside the general considerations on the subject of hydrogen, which finds ample space in the specialized and non-specialized literature, this work seeks to investigate a relatively new aspect: the possibility of using hydrogen as a fuel for electricity production in large plants. In this field, the interest in hydrogen is linked to the prospect of increasing the acceptability ("social acceptance") of new plants that could re-propose the use of fuels not well perceived by public opinion but available to a large extent, such as coal. The topic is of particular interest, both nationally and internationally, given the recent proposals to build highly efficient combined cycle power plants (e.g., the Porto Marghera "Hydrogen Park" project). From this assumption, the possible strategies for converting hydrogen into electricity are examined, trying to quantify both the efficiencies of the actual thermodynamic cycles and those of the entire conversion process.

Production of hydrogen from fossil sources and its use:

Hydrogen can be produced from fossil sources (natural gas, oil, coal) and renewable sources (wind, solar photovoltaic and thermal, biomass) and nuclear power through one or more specific processes. As for the use of hydrogen, there are many alternatives: even if the sector that probably arouses the greatest interest in public opinion today is that of transport, the civil sector seems equally interesting, in which hydrogen would find application in fuel cells in small-scale electrical generation systems. Some see hydrogen as an essential prerequisite for a definitive launch of renewable sources, but this will be, at least in short to medium term, only a marginal field.

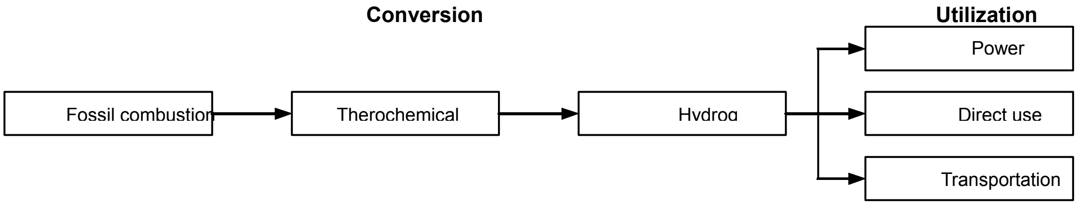

Figure 1. Use of hydrogen as an energy vector for the energy conversion of fossil fuels

The fundamental reason is inherent in the very nature of "renewable" sources, which have a very low energy intensity compared to fossils. The use of hydrogen, introducing an intermediate step between the source and the final product, only increases the problem.

On the other hand, if we consider large-scale production in conventional thermoelectric plants, a first significant transition to hydrogen is likely linked precisely to the use of fossil fuels (Fig. 1). The thermochemical processes of hydrogen production starting from fossil fuels are the only one's today that can be carried out on a large scale. In this case, a further problem has to be considered. It is true that hydrogen, once produced, in any system, it is used does not give rise to emissions, especially of CO2 but, in the case of production starting from fossil fuel, the problem is, in any case, shifted upstream of the system of use and precisely to the production phase [6].

Among the fossil fuels, the most interesting for hydrogen production are natural gas and coal: the first because it can be converted with higher yields, the second because it is the most available today of which the problem of massive exploitation. For the conversion of natural gas, the processes that are technologically mature today are steam reforming and partial oxidation, while thermoscissioning and steam reforming with CO2 sorbent are still in the experimental phase; the transformation of coal, on the other hand, is based on the gasification process [7].

Fig. 2 summarizes the steps required for the production of hydrogen from coal or natural gas; almost all lead to the production of a synthesis gas rich in CO, which to be enriched with H2 (and CO2) must react with water vapor through the slightly exothermic shift reaction ($\mathrm{CO + H2O \rightarrow H2 + CO2}$). After removing CO2, a gas-rich in H2 remains; the PSA (Pressure Swing Adsorption) unit is used to increase the purity of hydrogen [3]. Each process is associated with energy efficiency. The overall transformation efficiency of methane steam reforming can be between 65-85% depending on the operating parameters of the reformer and the quality of the heat recovery [4].

Coal gasification is achieved by passing a mixture of air (or oxygen) and water vapor through an incandescent solid carbonaceous bed (coal or coke). Water vapor has the purpose of exploiting the heat produced by the reaction of coal with air (or oxygen) to endothermically react with the coal itself and produce a mixture of carbon monoxide and hydrogen (synthesis gas). The removal of pollutants (particulate matter, chlorine, and sulfur compounds) is carried out downstream of the gasification process so that the syngas, cleaned and enriched with hydrogen in the shift reactors, can be sent to the PSA unit. The energy efficiency of the process is at lower levels than steam reforming of natural gas (partly because coal has a lower H/C ratio), oscillating between 50 and 60% [8].

Table 1. Thermophysical properties of hydrogen

PM	ρ [kg/m3]	Tcrit [K]	Teb [K]	PCI [MJ/kg]	PCI [MJ/Nm3]	PCS [MJ/kg]	PCS [MJ/Nm3]
2	0.08989	34	21	121	10.79	141	12.77

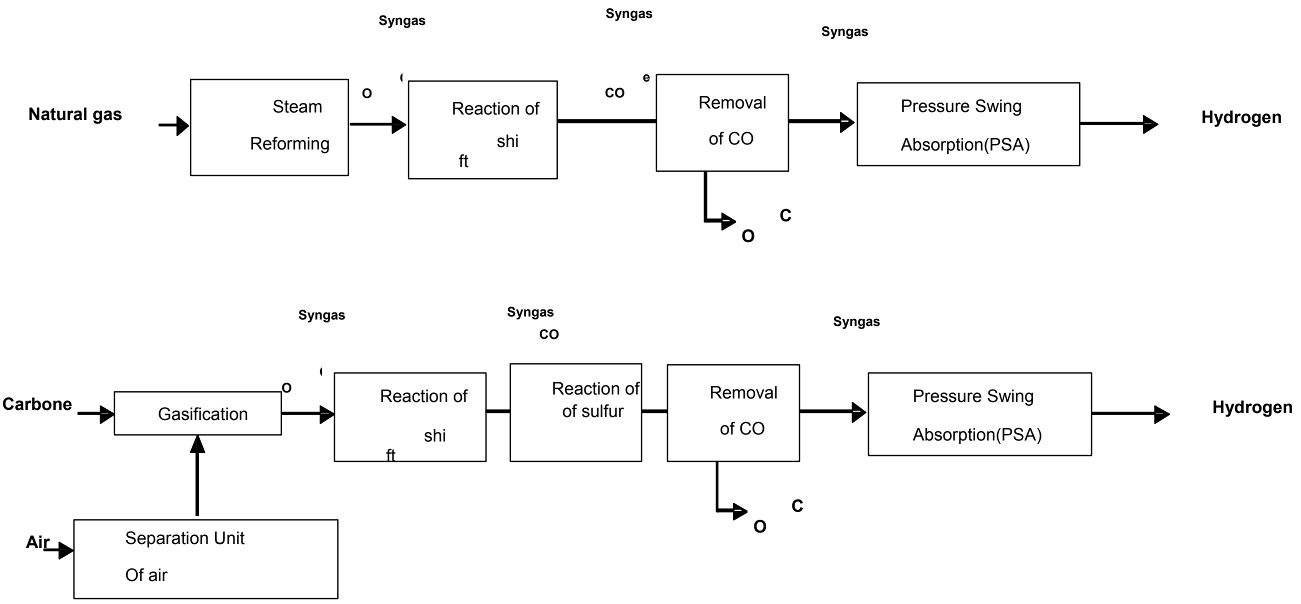

Figure 2. Hydrogen production processes from fossil fuels

2. Power generation in large plants using hydrogen

Hydrogen is an extremely versatile energy carrier with many possibilities of use. Among others, it can be exploited for the production of power in plants of different sizes, and more precisely, in fuel cells for applications that do not require more than a few hundred kW (distributed generation), or in turbogas or in combined and steam plants. Medium and large size. To obtain significant electrical powers and conversion efficiencies, it is necessary to use hydrogen in less conventional systems, providing combustion with air or pure oxygen.

The literature review has highlighted some interesting plant solutions that deserve further study, such as those proposed in the Japanese program WE-NET (World Energy Network), which analyzes a 500 MW plant [9, 10]. According to the data reported by the authors, the combined cycles “Topping Extraction Cycle” and “Bottoming reheat cycle” would allow obtaining electrical efficiencies (concerning the lower calorific value) of about 70%. (Table 2).

Table 2. Operational parameters for the three cycles of the WE-NET project [11]

Cycle	Bottoming	Topping	Rankine
Turbogas compression ratio	35.7	35.7	
Outlet pressure C.C. max (bar)	47.5	47.5	47.5
Outlet temperature C.C. max (° C)	1700	1700	1700
Outlet pressure CC turbo steamer (bar)	47.5		13
Outlet temperature C.C. turbo steam (° C)	1700	1700	1700
HP turbine inlet pressure (bar)	194	194	194
HP turbine inlet temperature (° C)	855	851	855
% steam flow in turbine for cooling blades	0.15	0.15	0.15
Condensing pressure (bar)	0.05	0.05	0.05
Total power (MW)	500	500	500

However, the project is futuristic since the combustion chamber operates at a pressure of 47.5 bar, and the turbine inlet temperature (TIT) reaches 1700 °C. The third configuration, the Rankine cycle, with two reheating of steam at 1700 °C and two regenerative exchangers working with fluids at temperatures above 1000 ° C, is similar to conventional high-temperature steam cycles and has a lower efficiency than the others. In the first instance, it is possible to evaluate the cycles similar to those proposed in the WE-NET project when operating with less stringent parameters.

3. Analysis of thermodynamic cycles operating with hydrogen as fuel

Having analyzed the most interesting solutions in the literature to convert hydrogen, let us hypothesize a possible solution classification. The simplest systems that can be conceived to use hydrogen as fuel in power plants are in any case represented by turbogas plants fueled by H2 - air, also in cogeneration configuration (Fig. 3 left), which can be traced back to the STIG (Steam Injection Gas Turbine). This is the steam injection produced by a recovery steam generator (GVR) downstream of the turbine, directly into the combustion chamber. This type of plant increases specific efficiency and power while not giving up the purely cogenerative characteristic of the particular configuration; the injection of steam into the combustion chamber limits NOx formation. A solution derived from this but more efficient can be that of the combined cycle (Fig. 3 right).

In perspective, however, the plants based on closed cycles fueled by H2 - O2 seem to be more interesting, which guarantees the complete elimination of any emissions by not providing for the release of any effluent into the atmosphere. The combustion of hydrogen with oxygen is “close” to stoichiometric conditions ($H_2 + 0.5O_2 \rightarrow H_2O$), so the only reaction product will be water vapor. Since combustion causes particularly high flame temperatures, it will be necessary to inject steam into the combustion chamber (STIG). For the plant to be closed, it is necessary, on the one hand, to bring the fluid back from the conditions of end expansion to those present in the combustion chamber; on the other hand, to have the flow rate constant, drain the steam produced by combustion. Fig. 4 (left) shows a simplified H2 - O2 closed loop diagram.

The gases downstream of the recovery boiler are compressed to be brought back to the combustion chamber pressure. In this case, the steam drainage also includes the flow of water that feeds the GVR. The steam produced in the boiler and that coming out of the compressor is mixed to be injected into the combustion chamber to control the maximum temperature. However, the extreme simplicity of the cycle does not allow for high performance: the minimum temperature of the cycle cannot drop below 100 ° C, since the minimum pressure of the cycle, to extract the steam to be drained without having to compress it, is the atmospheric one.

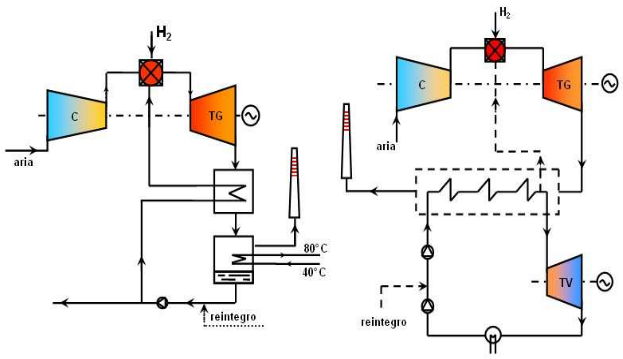

Figure 3. Cogeneration cycle and combined cycle fueled by H2-air

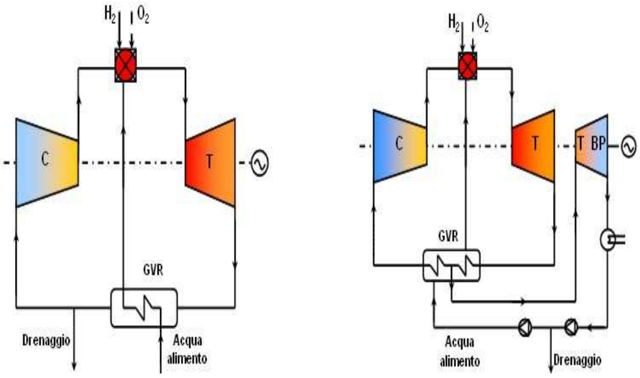

Figure 4. Simple H2-O2 cycle with a low-pressure turbine

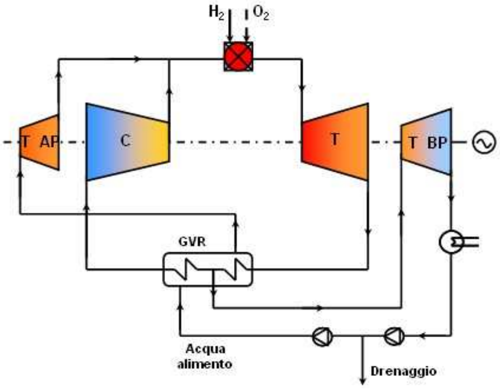

Figure 5. H2-O2 cycle with a high and low-pressure turbine

To increase the efficiency by reducing the compression work, the cycle can be modified (Fig. 4 right), compressing only a part of the fluid, while the remainder is made to expand in a low-pressure condensing turbine. Although better than the previous one, the solution is penalized by the inefficient heat recovery, carried out with a GVR at a pressure level linked to the combustion chamber.

A further improvement can be obtained by expanding the steam produced at high pressure in the GVR in a turbine before sending it into the combustion chamber (Fig. 5).

4. Thermodynamic analysis of advanced hydrogen-powered cycles

To analyze the plants' performance, it was first necessary to collect data on the thermodynamic properties of the substances involved. The air entering the compressor was considered a mixture of ideal gases in the following proportions: 21% of O2, 79% of N2 (dry air). Hydrogen was considered 100% pure. Polynomial expressions were used to calculate the various substances and mixtures (Bejan et al., 1996). For the study of the proposed plant models, use was made of a modular block representation (with concentrated parameters), i.e., the plants were schematized as a sequence of 'modules,' for each of which the mass flows and input and output energy, the characteristic equation of the transformation and the balance equations, also taking into account some typical operating parameters such as isentropic efficiencies.

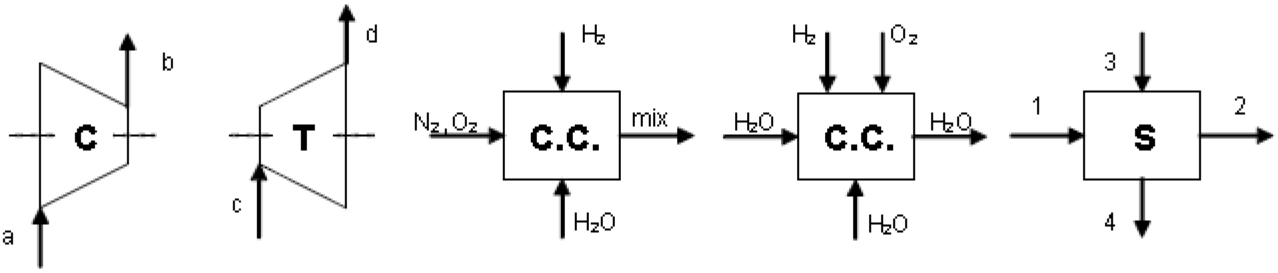

Figure 6. Elementary diagrams of the system components

Regarding the compressor and turbines, in addition to the compression ratio, only the isentropic efficiency was considered a parameter that characterizes them, which for simplicity has been kept constant as the compression ratio varies. The numerical values chosen, however, differ according to the technological goodness of each plant solution considered. Concerning the diagrams of Fig. 6, we have:

$$\eta_{is,c} = \frac{h_a - h_{b,id}}{h_a - h_b} \tag{1}$$

$$\eta_{is,t} = \frac{h_c - h_d}{h_c - h_{d,id}} \tag{2}$$

$$l_{compressore} = h_a - h_b \tag{3}$$

$$l_{turbine} = h_{c,mix} - h_{d,mix} \tag{4}$$

The combustion chamber was assumed to be thermally insulated from the outside, and the process inside it was assumed to be isobaric, neglecting the pressure losses of the working fluid. The combustion was also considered complete, and therefore the mixing enthalpies between the components of the mixture, the dissociation of the products, and the formation of intermediate and polluting compounds (NO_x, etc.) were neglected. The equation that regulates the process is the enthalpy balance of the species present:

$$\sum_R N_R\left(h + h_{form} - h_0\right)_R = \sum_P N_P\left(h + h_{form} - h_0\right)_P \qquad (5)$$

R is the reactants (N2, O2, H2, and H2O, respectively) and P the products (N2, O2, and H2O).

The molar enthalpies, functions of temperature, are obtained for the various substances from polynomial expressions [12].

The exchangers examined were single flow (represented on the right side of Fig. 6) and two flows parallel. Single-phase (economizers and superheaters) and two-phase (evaporators and condensers) banks were analyzed. The union of several banks forms an exchanger as a whole; for each exchange section, the enthalpy balance and flow conservation equations were set. Concerning the diagram of Fig. 6, which can represent a generic single flow section, we have:

$$m_1(h_1 - h_2) = m_3(h_4 - h_3) \qquad (6)$$

The simplifications adopted for the heat exchangers were in addition to perfect adiabaticity, defined by Eq. (6), even assuming head losses equal to 1% of the inlet pressure. The constraint was also assumed to limit the minimum temperature difference between the operating fluids (pinch-points) to 10 ° C. Concerning the elementary schematizations of Fig. 6 and equations (1) - (6), various plant configurations derived from the simplified diagrams shown in Fig. 35 have been examined, referring to different conditions of the fluid entering the compressor (air or steam) and to the turbine (steam or air-steam mixture). More complex is the analysis of the combustion chamber and the various exchangers (sections of the GVR, condenser, and desuperheater), given the different compositions and operating conditions of the fluids.

5. Results and Discussion:

This paragraph shows the simulations' results considering the plant layouts of hydrogen-air cogeneration turbogas plants or hydrogen-oxygen closed-cycle plants. Particular attention is paid to evaluating cycle efficiencies as a function of turbine inlet temperatures (TIT) and certain operating pressures. For simplicity of analysis, a constant flow rate of 1 kg / s of H2 is considered a reference figure.

5.1 Analysis of an H2-air cogeneration turbogas plant

First of all, an example of using hydrogen for cogeneration in medium-sized turbogas plants is analyzed; to make the evaluations, the operating parameters of turbines on the market were considered. The plant layout is the one shown on the left side of Fig. 3. The fumes leaving the turbine to enter a GVR where the steam to be injected into the combustion chamber is produced. The residual enthalpy of the gases is used in a desuperheater-condenser to satisfy a thermal user (which can ideally serve a district heating network) that requires water at 80 ° C. The condensed water flow is recycled and, after reintegration, pumped back into the GVR. It was assumed - isentropic efficiency of the compressor $\eta$is, c = 85% and of the turbines $\eta$is, t = 86%. Some tests were carried out by varying the turbine inlet temperature (TIT), then the compression ratio, and then the air-vapor ratio (Rav) to be introduced into the combustion chamber. The values of 1200 ° C and 1300 ° C have been chosen for the TIT, while the compression ratios have varied between 12 and 30. The Rav varies from a maximum of 20 to a minimum compatible with the vapor producibility of the GVR respecting the constraint on the minimum pinch-point of 10 ° C. Fig. 7 shows the trend of the electrical and cogeneration efficiency for the case with TIT equal to 1300 ° C, as the Rva (= 1 / Rav) varies and using the compression ratio as a parameter. It is observed that the curves of the electrical efficiency have a monotonous trend that increases as the steam/air ratio increases up to the value corresponding to the maximum Rva obtainable by respecting the pinch-point in the GVR. The main advantage deriving from the use of STIG technology is the decrease in the necessary airflow and, therefore, in power required by the compressor (considering the pumping power to be negligible). The combustion of hydrogen would require a large excess of air to keep the temperature within the established limits, air which in the STIG is partially replaced by steam with greater specific heat. Table 3 shows the results obtained for TIT 1300 ° C, compression ratio β = 30, combustion chamber injection temperature 540 ° C. It is noted that the power absorbed by the compressor is a significant fraction of the power obtained in the turbine, which decreases with the increase in Rva. Considering the cogeneration efficiency, from the graph, unlike the electric one, it undergoes a significant decrease as the Rva increases. At the same Rva, higher electrical efficiencies are obtained for increasing compression ratios while thermal energy production is reduced.

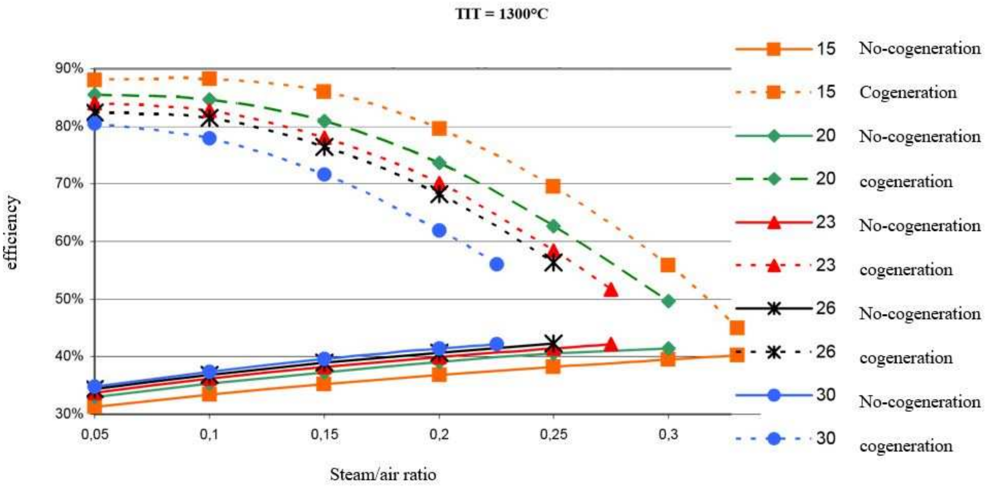

Figure 7. Electrical and cogeneration efficiency of the H2-air system schematized in Figure 3

Table 3. Results obtained for TIT equal to 1300 ° C, β = 30

Rva	m□air	W□comp (MW)	m$_{vap}$ (kg/s)	m□turb (kg/s)	W□turb (MW)	W□tot (MW)
0	97.4	55.3	0	98.5	93.1	37.8
0.050	87.9	49.9	4.4	93.4	91.6	41.7
0.100	80.1	45.5	8.0	89.2	90.4	44.9
0.150	73.6	41.8	11.0	85.7	89.3	47.5
0.200	68.1	38.3	13.6	82.7	88.4	49.7
0.225	65.6	37.2	14.7	81.4	87.8	50.6

However, it should be noted that, if on the one hand, it is true that cogeneration efficiencies of up to almost 90% are achieved, it is equally true that the two forms of energy (electrical and thermal energy of water at 80 ° C) have an extremely exergetic level. Plants of this type (e.g., Hydrogen Park project in Porto Marghera), although interesting from a thermodynamic point of view, may only have a demonstrative character in the short-medium term since they do not allow the exploitation of hydrogen in the most effective way (the, however, the use of hydrogen to produce hot process water seems inappropriate); perhaps the best is the plant configurations aimed at producing power.

5.2 Analysis of H2-O2 closed cycles

The first scheme to which reference is made (Fig. 8) takes up the "Topping extraction cycle" configuration (of the WE-NET project) but setting the compression ratio and the turbine inlet temperature to values closer to those of the machines current, while the pressure of the GVR (equal to 180 bar), which is the most advanced component of the system, is brought to the highest values.

Subsequently, a plant-derived from the first was analyzed (Fig. 9), i.e., with the same parameters as the turbogas, but the heat recovery pressure is restricted to the minimum value to feed the steam produced directly into the combustion chamber. This system is very similar to the previous one, but there is no high-pressure turbine. It also has the limiting factor represented by the fact that heat recovery is done with a single pressure level in the GVR, limited to 29.4 bar. Finally, in the third solution (Fig. 10), neither of the two parameters is constrained, and a cycle is analyzed, which, on the one hand, is characterized by a compression ratio higher than the first two (more advanced turbogas), on the other by a GVR conventional with two pressure levels instead of just one.

The distinctive element of this system lies in the two pressure levels, 47.5 and 110 bar, values that GVR easily reaches on the market. As further operational parameters, common to all three configurations, have been chosen

- Condensing pressure = 0.05 bar
- Isentropic efficiency of the compressor and turbines ηis, c = ηis, t = 89%

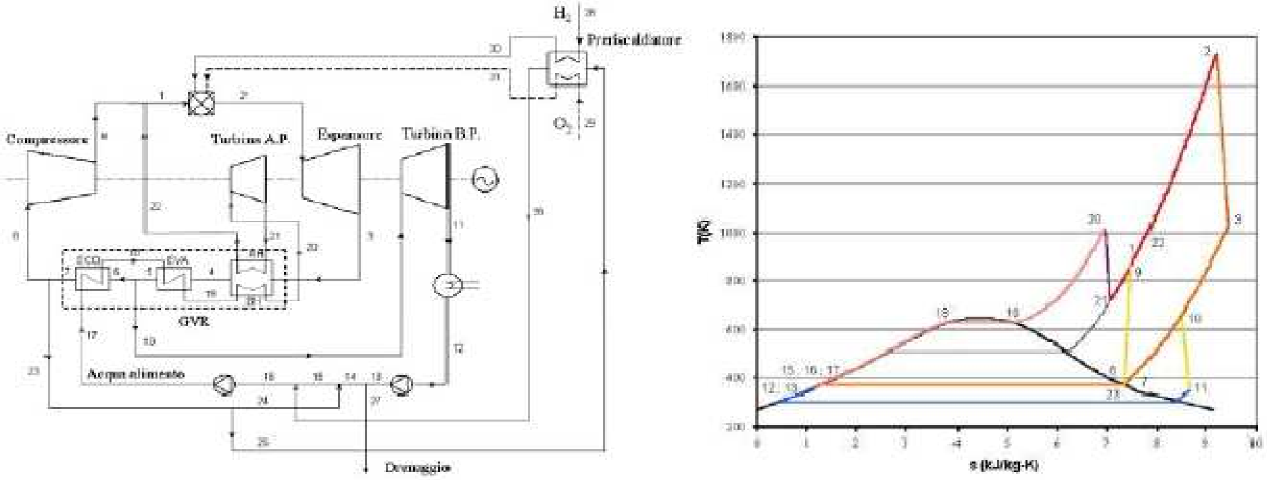

Figure 8. System diagram with a high-pressure turbine (GVR at 180 bar)

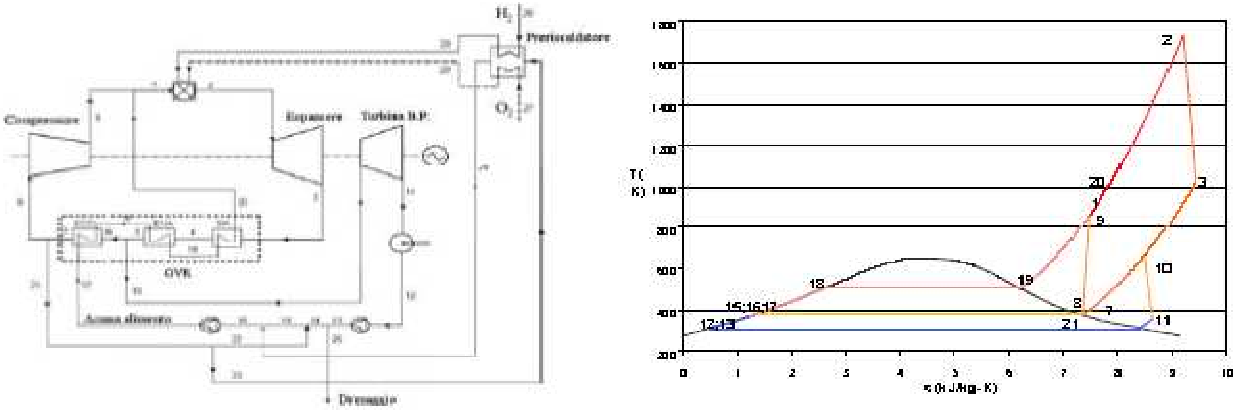

Figure 9. A system without a high-pressure turbine (GVR at 29.4 bar)

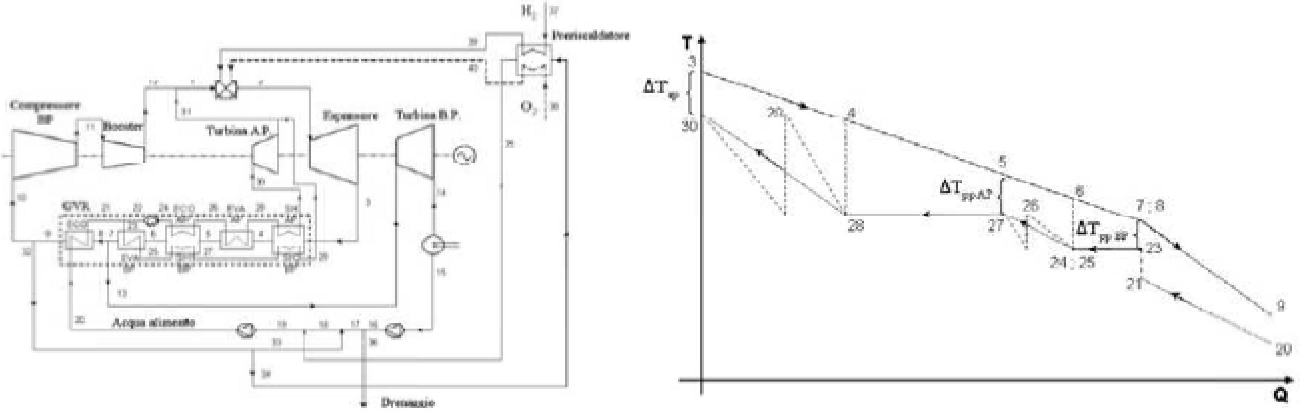

Figure 10. A system with two pressure levels of the GVR (GVR at 47.5 and 110 bar)

In the simulations carried out, the turbine inlet temperature (TIT) was varied between 1200 ° C and 1550 ° C, keeping the compression ratios and the flow rate of 1 kg / s of hydrogen constant. This temperature range was chosen since TIT of 1200 ° C already represents a consolidated standard; on the other, TIT of 1500 ° C should be reached in the short-medium term using H series turbines. The conclusions of the analysis are summarized the yield values as a function of the TIT. The results obtained for the three plants' performance are shown in the graph in Fig. 11, noting that the last solution has the highest performance only for TITs greater than 1600 ° C. For lower values, the yields are lower than those of the system with a GVR supply pressure of 180 bar; it is also noted that the slope of the third curve is attenuated for higher TITs; at high compression ratios, lower turbine exhaust temperatures correspond which penalize the performance of the underlying cycle.

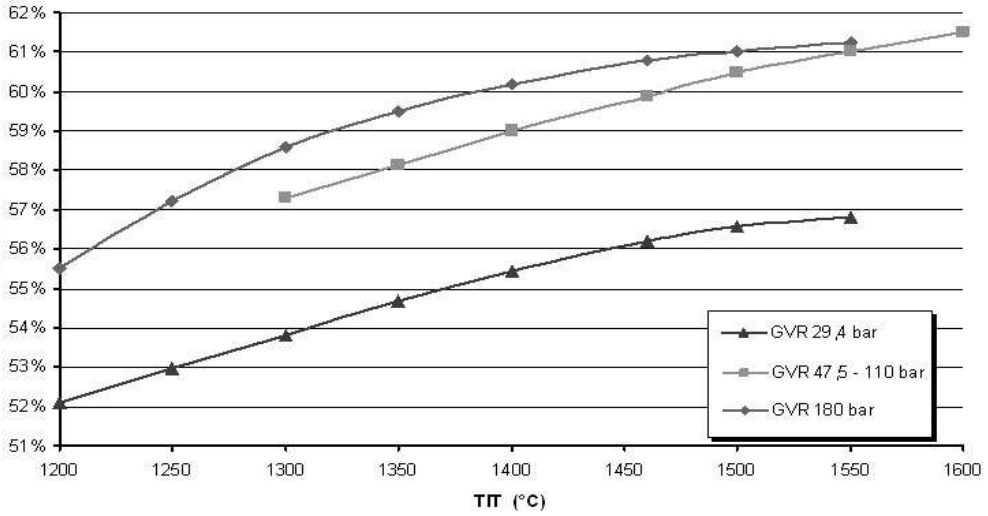

Figure 11. Comparative analysis of the three plants analyzed

Table 4. Comparative data of the production of electricity from fossil fuels with hydrogen

H2 production with CO2 sequestration	**Electrical efficiency of H2 cycles**		**Over all return**	**Current technologies**
77- *Natural gas* 80%*(steam reforming)*	Turbogas (cogenerativo) open cycle (TIT=1300°C)	**42 %**	**34%**	Combined cycle plants 58-60%
	Turbogas + GVR a 180 bar a closed loop (TIT=1460°C)	**61 %**	**49%**	
	Turbogas + GVR a 194 bar a closed loop (TIT=1700°C)	**70 %**	**56%**	
Carbon* 57-60% *(gasification)	Turbogas (cogenerativo) open cycle (TIT=1300°C)	**42 %**	**25%**	IGCC plants 42 - 46%
	Turbogas + GVR a 180 bar a closed loop (TIT=1460°C)	**61 %**	**37%**	
	Turbogas + GVR a 194 bar a closed loop (TIT=1700°C)	**70 %**	**42%**	

5.3 Discussion of the results

From the analysis of the data shown in Fig. 11, it can be deduced that, only by betting on the technological advancement of materials and cooling systems that bring the TIT up to 1700 ° C, it seems convenient focus on plant solutions of the type shown in Fig. 10. Still, at the current technology levels and also those that can be hypothesized in the next ten years, it seems more convenient to focus on recovery configurations at a single pressure level and try to carry out thermal recovery at rather high pressure. To conclude, table 4 shows an overall picture of the conversion efficiency obtained using hydrogen produced from fossil fuels in plants such as those analyzed in the previous paragraph. Three different levels are reported: that of the cogeneration plant, those of the most advanced plants conceivable in the medium term (TIT = 1460 ° C), and future plants (TIT = 1700 ° C). The yields of the methane steam reforming and coal gasification processes are also reported. From the product of the conversion efficiency of the fossil fuel into hydrogen and the hydrogen-fueled cycle, it is possible to derive plausible values for the overall efficiency of conversion into electricity of the two fossil sources passing through hydrogen. While power conversion plants are still a long way off, H2 production technologies are mature, even if they are susceptible to improvements from an energy point of view. Considering the results reported in Table 4 as a whole, it is interesting not so much the absolute value of the global yield, at the technical levels that can be assumed today equal to 49% for natural gas and 37% for coal, but rather the comparison with technologies plants used for the generation of power from methane and coal (combined cycle plants and IGCC respectively). By making this comparison, it can be said that the production of hydrogen from natural gas is unattractive when compared with the direct use of fuel in combined cycle plants (which, among other things, will evolve to a further extent in the coming years)[13, 14].

Despite the lower overall efficiencies of the process, the entire chain of electricity production starting from coal seems much more interesting. The cycles that use hydrogen produced from coal represent an alternative of comparable complexity compared to existing IGCC plants, with lower environmental impact and higher efficiency, given that in the future they will be able to reach, by burning the hydrogen produced, maximum cycle temperatures that cannot be reached. from the combustion of syngas in IGCCs or to lend themselves to interesting co-production solutions [15].

6. Conclusions:

The advent of the “hydrogen era,” which public opinion, exceeding optimism often considers near and foregone, actually raises numerous questions that are still open today. Hydrogen will have to be produced mainly from fossil fuels, primarily natural gas and coal. The processes we will orient ourselves shortly will be steam reforming for the first and gasification for the second.

As for the uses of hydrogen, in addition to the well-known one in the transport sector, the one aimed at producing power in large plants is probably also interesting. Some advanced plant configurations are analyzed in the open cycle (hydrogen-air) and closed-cycle (hydrogen-oxygen) configurations in this context. The yields of the cycles analyzed can range from levels of the order of 40% (in open-cycle configurations) to levels of the order of 60-61% in the more advanced closed-cycle configurations. At present, the overall efficiencies of electricity production from coal and natural gas through hydrogen in advanced thermodynamic cycles are 37 and 49%, respectively. Only in the perspective of the diffusion of more advanced turbines, with TIT of the order of 1700 ° C, could overall efficiencies comparable to those of the usual conversion technologies be achieved.

Analyzing the problem as a whole, it can be observed that electricity generation from hydrogen obtained with high yields from natural gas. However, it appears to be the most thermodynamically efficient option, is not very attractive compared with current technologies for the use of methane or gas. Nature is represented by combined cycle plants, characterized by less complexity and still excellent development margins (thanks to the ever-higher turbine inlet temperatures). On the other hand, integrated coal-fired plants seem more interesting because they represent an alternative of comparable complexity, with lower environmental impact and similar efficiency than IGCC plants (technology not fully consolidated and which today reaches efficiencies of 43%) if not even higher in perspective.

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