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HYDROGEN AS AN ENERGY VECTOR: NEW FUTURE PROSPECTS FOR APPLICATIONS OF NUCLEAR ENERGY

by

G. BEGHI

1972

Joint Nuclear Research Centre
Ispra Establishment - Italy
Materials Division

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Among the hydrogen production processes, the method of dissociation of water with a closed cycle of chemical reactions and utilising nuclear heat seems particularly promising.

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ABSTRACT

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KEYWORDS

HTGR TYPE REACTORS
PROCESS HEAT REACTORS
HYDROGEN
ENERGY
PRODUCTION
DECOMPOSITION
WATER

CONTENTS

HYDROGEN AS AN ENERGY VECTOR : NEW FUTURE PROSPECTS FOR APPLICATIONS OF NUCLEAR ENERGY *)

1. Diversification in the applications of nuclear energy

That the availability of energy is a factor essential to technical progress, and has always been the fundamental necessity of every new development of society, is well known. We have only to consider the correspondence between per capita energy consumption and the gross national product in different countries to see an obvious relationship between energy consumption and the standard of living.

Problems connected with energy in general therefore figure largely as the subject of studies and forecasts.

An examination of the evolution of various primary sources of energy (wood, coal, petrol, water, natural gas, nuclear energy, etc.) shows that over the past hundred years there has been considerable variation in their relative distribution (1). Technological developments have brought about radical alterations, and an obvious factor is the rate at which trends themselves are changing. The period 1980–1990 will probably be characterized by noticeable variation in the percentages of the different primary sources of energy being used to satisfy the energy requirements of society (2) (3).

Nuclear energy should be able to play an important role in this development (4) since the advantages of uranium as a primary source are already recognized (5). But it is above all in the long-term forecasts that the growing need for energy will have to be largely supplied by fast breeder reactors (and in the future perhaps also by thermonuclear fusion reactors).

*) Manuscript received on April 5, 1972

Such an expansion of nuclear energy will be increased if and when it is made polivalent. In fact, heat developed by nuclear reaction is used at present only for the production of electricity, and at the present time less than a quarter of all primary energy sources is used for producing electricity (6) (7). We must therefore extend the possible applications of nuclear energy to include its utilization for industrial processes, either directly or by means of intermediary energy sources other than electricity. Studies are progressing in both these directions, but it is of the second possibility that we wish to speak here: an alternative intermediary energy source. In addition to the above reasons the usefulness of an intermediary energy vector is also based on the large size of nuclear power stations, as required for an economical interest. For this reason the nuclear energy is available in the form of heat only in large plants, and in large quantities. Conversely, most of the demand for energy is diffused and involves small quantities, and it is here that a flexible intermediary, or vector, either for transport or capillary distribution according to requirements, becomes necessary.

2. Hydrogen as an intermediary energy source

Of all the possible solutions to this problem, one stands out as being particularly interesting: hydrogen. The main reasons why this element would be suitable for the transfer of nuclear energy in a variety of ways are as follows:

- its wide range of possible uses, in very varied sectors of the energy requirements field.
- The "clean" burning of this fuel, which makes it interesting from the pollution point of view. It is unnecessary to emphasize here the growing importance, if not to say necessity, of this factor, in a technologically advanced society, with a high consumption of energy per capita (8).

- Methods and facility of transport: networks for the transfer of hydrogen between chemical and petrol-chemical industries already exist (9).

- The extent of present consumption. Approximately 50 billion cubic metres (10) were consumed during 1967 in the European Community countries.

  In addition, because it is involved particularly in the production of ammonia, the necessary quantities of H_2 are already concentrated within large installations. The largest of these plants are at present producing 600.000 - 900.000 tons per year of ammonia (11), with a corresponding consumption of hydrogen of 4-6 millions cubic metres per day. Even the earliest attempts to enter the market would involve hydrogen production in large quantities.

- The technology of energy consumption is turning increasingly towards the use of gaseous fuels. For instance, natural gas which supplied 6,3% of the energy requirements of the European Community in 1968, will supply 8,5% in 1971 (12).

  From the utilization and transport points of view, hydrogen can be considered to be in line, directly or indirectly, with the evolution of energy technology.

3. Hydrogen requirement in the future

The interest of an intermediary to develop exploitation of nuclear energy naturally depends upon the range of usefulness of the intermediary itself. Hydrogen is in a favorable position from this point of view as well. The future of its development can be considered under two headings:

a.- the projected development of its present uses,

b.- its potential uses.

As far as its present uses are concerned, the following can be cited as the most important: ammonia synthesis, production of chemical products in general (metanol, organic compounds, etc.), and the hydrodesulphurization and hydrocracking of petroleum products (13). On this last-mentioned subject, there is a trend towards a further increase due to stricter enforcement of legislative requirements regarding the sulphur content of petrol-derivative fuels; since the sulphur is removed by means of hydrogen, the refineries tend to show a deficit of hydrogen in their balance (14) (15).

All these hydrogen consumptions involved by the present utilizations are in development, and would therefore be in favour of an increased demand (16).

An estimate of the future of the potential uses of hydrogen is of course more difficult to make, in view of the rather uncertain criteria involved.

It is nevertheless possible to see in which directions these potential applications are most likely to develop.

- The field of iron metallurgy is the first one: many studies are already in progress for the direct reduction of iron ore and to put the already defined processes into commercial practice, (17, 18, 19). The reducing agent would be hydrogen, but before this technique can be employed on an industrial scale, a research and development effort is still necessary. However, the future perspective for this reducing technique seems favorable, in comparison with that of coke.

- One field which may have interesting development possibilities to offer is the hydrogenation of fossil fuels, for the reduction of light hydrocarbons and various other chemical products (20) (21) (22) (23). This field may lead, amongst other things, to an increase in the importance of coal as a primary source of energy, by trasforming it into hydrocarbons, which are easier to use and clean (sulphur is eliminated). The carbon gasification aspect seems to be attracting a considerable amount of attention [24] [25]. Nor should we forget the transformation, which can also be done with hydrogen, of liquid hydrocarbons into gas products (synthetic pipeline gas).

These processes would be able to take advantage of already well-developed techniques for the distribution and utilization of gas fuels, (natural gas) [26] [27].

Long-term development projects might also be envisaged here.

- Space technology has contributed towards developing the use of hydrogen, and will probably influence the future development of aerial transport [28, 29, 30]. The technical characteristics of hydrogen are interesting for a fuel for jet aircraft.

- Because of atmospheric pollution, for which vehicles are largely responsible, there is an urgent need to make use of "clean" fuels. Hydrogen would be particularly indicated in this context, and several encouraging conclusions have been reached from research already carried out in the United States, where legislation on this subject is particularly strict [31] [32] [33] [34].

- Additional long-term prospects can be envisaged, such as, for example, the utilization of hydrogen in fuel-cells, to supplement the electricity production in the peak periods [35]. In these cases the applications are dependent upon the development of other technologies and it is difficult to make quantified forecasts involving interconnected factors.

As a conclusion, it can be claimed that hydrogen is of positive interest to various sectors of the field of energy ranging from technological applications to the reduction of atmospheric pollution [36] [37] [38] [39] [40]. All the considerations set out here are primarily of an indicative nature, even though some evaluation has been attempted. T.A. MILLS and J.S. TOSK, of the U.S. Bureau of Mines [39] have estimated the values of hydrogen production in the USA for the year 2,000. If we extrapolate the present consumption according to the trends of the past five years, we obtain a value of 300 billion cubic metres annually. If we also take into account the incidence on hydrogen consumption of techniques such as the production of liquid and gaseous fuel from coal and heavy hydrocarbons, the direct reduction of iron ores, and the increase of hydro-desulphurization and hydrocracking, we obtain an estimate of between 400 and 1500 billion cubic metres, for the annual production in the USA.

Event with all their implicit limitations, it is nevertheless quite obvious that at least some of these lines of development will have great medium- or long-range potential: they satisfy particularly well the necessity of limiting atmospheric pollution and are connected to technologies that will play an important part in the developments of technologically advanced societies.

4. Hydrogen production methods

The methods most widely employed at present for industrial hydrogen production are [41]:

- steam-reforming of liquid or gaseous hydrocarbons,
- partial oxidation of hydrocarbons.

Hydrogen of high-grade purity can also be obtained by electrolytic processes; however, the production costs of these processes are noticeably higher than those of other methods.

The hydrogen production processes are more or less easily adapted to the utilization of nuclear energy.

In the hydrocarbons steam-reforming process, and in particular that of natural gas, instead of supplying the reaction heat with the part of the same gas that is used as fuel, a helium circuit can be used to transfer the nuclear heat of the reactor to the chemical installations.

In the electrolytic processes, the nuclear energy can be introduced as electricity, which is the basis of this water dissociation process.

Water dissociation offers several advantages over the present hydrogen production methods, which are based on hydrocarbons, in so far as it eliminates a raw material involving supply and cost problems, etc.

Water dissociation, in addition to the electrolytic method, which involves a chain of transformations from thermal energy to mechanical and electrical energy, can also be obtained by chemical methods, using heat alone. Thermal dissociation of H_2O occurs at temperatures of about 2500°C; in order to remain within the temperature range technologically feasible for a nuclear reactor, it must be possible to obtain dissociation at temperatures below 800°C. For this it is necessary to pass through various stages, with cycles of several chemical reactions [42].

This process has the advantage of needing only water as a raw material, and of using nuclear energy as a direct heat source for the chemical reactions, i.e., without any intermediate stages. The process must of course be economically competitive.

One point should be mentioned, which concerns any water decomposition process: - a certain quantity of oxygen is obtained as a "by-product", although there is no continuous discharge of poisonous products.

Oxygen has a market of its own, and various uses [43], not to mention its possible usefulness as an agent for the treatment and transformation of polluting industrial waste products; in the future this aspect of the oxygen will assume an ever-increasing value.

5. Chemical decomposition of water

This method of producing hydrogen deserves a special mention, because, although it has not yet been applied to industrial processes, plans to combine it with nuclear reactors look rather promising, since it only requires heat.

The chemical dissociation of H_2O, as mentioned in the previous paragraph, can be obtained at temperatures technologically feasible for nuclear reactors, by means of various chemical reactions thermally activated at temperatures below that of the direct dissociation of H_2O. This means that the decomposition of the water is achieved with a series of chemical reactions in closed cycles which give the sum:
$H_2O = H_2 + \frac{1}{2} O_2$.

The Joint Research Center of the European Community is at present working on this subject. Various possible cycles are under study, and several are in the experimental stage. One cycle has even been defined and patented under the name of Mark-I (44) (45). In this cycle the water reacts, in order to obtain an acid and a base: the acid attacks a metal and releases the hydrogen, whereas the base is used to form an oxide which liberates the oxygen as it decomposes. The chemical elements employed for this are calcium, bromine and mercury: these elements circulate in closed cycles in the process, and are regenerated in the various reactions.

Other possible chemical cycles for extracting hydrogen from water are very similar in type. The studies at present in progress are still at a preliminary level, and the purpose is to carry out continuous experimentation, on a laboratory scale, of the most promising chemical cycles. It is possible then define and choose the cycle which, from an economical point of view, seems to be the most promising for employment in industrial processes, and which would also operate at the temperatures foreseeable in the medium-term development of nuclear reactors. The type of reactor most adapted to supply heat at high temperatures for chemical processes is the "high temperature gas reactor" (HTGR). In these reactors it is foreseen that the circulating helium can reach a maximum temperature of about 1000°C.

6. Conclusions

From observations made in the preceding paragraphs the following two points have emerged clearly:

- Hydrogen has great future potential as an interesting energy vector from the point of view of its variety of uses, and its foreseeable consumption. An important factor in the future of hydrogen is its usefulness in the environmental pollution control.
- The future prospects for a hydrogen production process, based on chemical decomposition of water, is good; such a method would require only heat at temperatures at which nuclear reactors could supply it. With this prospect nuclear energy might take over a greater share of the energy market in which it figures so far with electrical energy only.

*) The texte is the English version of an article requested for publication in the italian review GAS.

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Alfred Nobel

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