**PROSPECT OF HTGRs FOR HYDROGEN PRODUCTION IN INDONESIA**

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**Abstract**

Hydrogen energy system is interesting to many peoples of the world that because of hydrogen promised to save our planet earth from destroying of burning of fossil fuels. The selected development of hydrogen production from water such as electrolysis and thermochemical cycles are evaluated. These processes are allowed to split the water at lower temperature, still in the range of HTGRs' working temperature. An overview of related studies in recent years enables the development of research to be followed, studied and evaluated are mentioned. The prospect of hydrogen market in Indonesia and economic consideration based on previous studied are also analyzed and evaluated.

# 1. INTRODUCTION

## 1.1 Background

Today, more than 80% of the world's energy demand and supply are depending on fossil energy resources (coal, oil, natural gas). The rate of using fossil energy resources tends to increase sharply. Soon or later energy crisis will come, likely what happened in oil embargo experience in 1973. The embargo itself has a good impact to the people of the world that the oil is not abundant and need to do some saving for the next generation.

The above consequences are also valid for Indonesia even as member of OPEC. In the last Bali's OPEC conference has achieved some agreements of oil production balance in each country's members. Indonesia has allowed to produce its oil up 1.4 million barrel per day [1,4]. But unfortunately the non-renewable energy reserved of Indonesia (included oil reserved) are so limited as shown in Table 1. And it is estimated that in the beginning of 21st century Indonesia will be become net importer oil country.

It is also considered that gradually the level of pollutant contents (CO, $CO_2$, $SO_x$, $NO_x$ etc.) in the atmosphere are increasing as because of burning of fossil fuels[2,3,7,8]. All these pollutants are resulting global warming, acid rain, and seriously damaging the biosphere of the earth.

**Table 1 The availability of energy resources in Indonesia**

| No | Energy source | Proven Reserved | Production rate per year | Final reserve estimation - [4] |
|---|---|---|---|---|
| 1 | Natural gas | $91x10^{12}$ SCF - [1] | 6% | 2026 |
| 2 | Oil | $10.9x10^9$ barrel - [1] | 0% | 2006 |
| 3 | Coal | $36x10^9$ ton - [2] | 12.4% | 2166 |
| 4 | Peat moss | $8x10^9$ ton - [3] | - | - |
| 5 | Solar | - | - | - |
| 6 | Wind | - | - | - |
| 7 | Water | $75x10^3$ MW | - | - |
| 8 | Geothermal | $16x10^3$MW | - | - |
| 9 | Biomass | - | - | - |
| 10 | Marine | - | - | - |

[1]) Petroleum report, 1993
[2]) Coal Directorate, Ministry of Mine and Energy, 1992
[3]) New and Renewable energy resources Conference, Kenya, 1981
[4]) Markal study, BPPT, 1993

## 1.2 Future clean energy system

In the concept of future energy system, the primary energy source should be high abundant and limitless. Nuclear with its fast breeder - fusion and solar energy are considered as two candidates for long-time primary energy sources [1,3,7].

In order to increase the flexibility using of the primary energy sources, it need an energy store that acts as a go-between (or intermediary) between the primary energy sources and the consumers (industry, transportation, household). This intermediary energy is comply with all requirement of the present and future conditions such us:

It must be storable and transportable,
It must be fuel for use in transport systems, home and industry,
It must be clean and inexhaustible.

It is only hydrogen and electricity meet with all the above requirements. Hydrogen is certainty one of the keys to "clean energy". Hydrogen is able to replace all the positions of fossil fuels. It can operate cars, homes and various businesses from environmental clean, renewable energy source on large scale.

## 1.3 Nuclear heat as energy source

HTGR is potential to used to non-electric applications as well as the electricity generation as a high temperature heat source up to 1000°C. Heat energy is possible to use in hydrogen and methanol productions, enhance oil recovery, coal liquefaction and desalination processes.

At present, Japan and China are constructing HTGR with its thermal out put 30 MW and 10 MW respectively. The Japanese HTGR (popular as HTTR) is planned to be first critically in 1998 and to be connected to heat utilization processes in the year 2003. Of this HTTR thermal out put of 30 MW, 10 MW is transferred to be heat utilization system through a helium -to- helium intermediate heat exchanger as shown in Figure 1.

The purpose of this paper is to report the current status hydrogen production and utilization in Indonesia. It is also described the role hydrogen energy in the future related to the application nuclear heat (HTGRs) as input energy source.

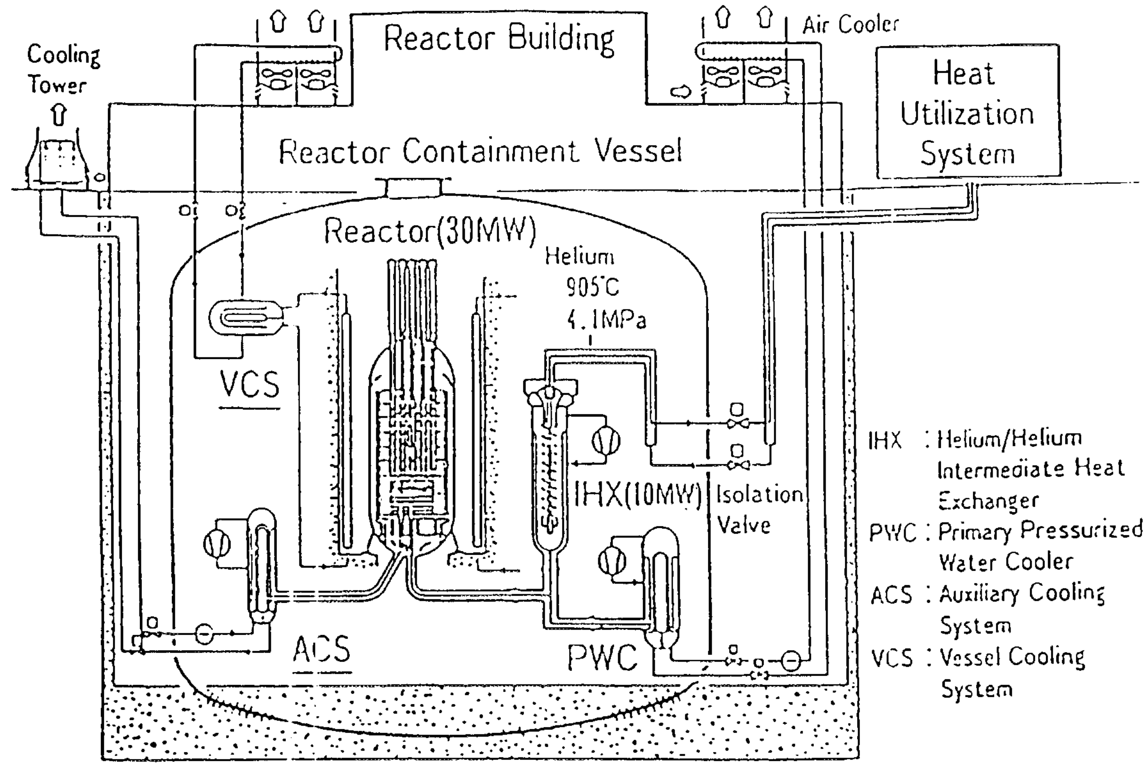


**Fig. 1 Connection of heat utilization system to the HTTR reactor cooling system [6]**

## 2. HYDROGEN PRODUCTION

### 2.1 Conventional hydrogen production

The world's hydrogen production is still derived from fossil, almost the total hydrogen demand is met by hydrogen made from fossil fuels, by steam reforming and by partial oxidation of natural gas or oil fractions.

Briefly outlined, these include [1,2,4,]

(1) Removal of methane and other constituents from refinery tail gases or coke oven gas at low temperatures.

(2) Reforming of natural gas ( or other hydrocarbons)

$$CH_4 + H_2O = CO + 3H_2 \qquad (1)$$

followed by water-gas shift:

$$CO + H_2O = CO_2 + H_2 \qquad (2)$$

This is followed by carbon dioxide removal using physical or chemical absorption techniques.

(3) Direct production of synthesis gas by reaction of coal with oxygen and steam

$$3C + O_2 + H_2O = CO + H_2 \qquad (3)$$

followed by water-gas shift and carbon dioxide removal.

(4) Partial oxidation of hydrocarbons

$$CH_4 + 0.5\ O_2 = CO + H_2 \qquad (4)$$

followed by water-gas shift and carbon dioxide removal.

Of these methods, that of (2) is the most widely employed. Desulphurized natural gas is steam reformed in the presence of a nickel oxide catalyst. After cooling to about 375°C, the product gases undergo the water-gas shift reaction, usually with an iron/chromium catalyst. And this shift reaction may be carried out at about 200°C over a copper/zinc catalyst. The carbon dioxide is removed by physical or chemical adsorption. Overall, the thermal efficiency of the process approaches 70%.

Hydrogen plants in Indonesia are commonly located closed to oil and gas fields such as Balik papan and Dumai plants as shown in Table 2. Hydrogen produced in these plants are used in oil refinery for hydrocracking, hydrotreating and hydrorefining, ammonia plant for urea fertilizer industry, hydrogen peroxide and methanol production etc. [1,10,11].

## 2.2 Future interested hydrogen production system

In comparison, the hydrogen production from water as raw material is more interesting than fossils. Among of those reasons are the water has high abundant. 75 per cent of the earth planet consist of water. Water also could be recycled from the burning of hydrogen fuels. And water is relatively clean, a hundred per cent free carbon element.

The production of hydrogen from water could be done by thermolysis, thermochemical cycle, electrolysis and photolysis. Based on the present technology, electrolysis and thermochemical cycle are more reasonable ways and promised a good prospect in the future for hydrogen production.

**Table 2 Hydrogen production plant in Indonesia**

| No | Location | Capacity (MMSCF)[5] |
|---|---|---|
| 1 | Balik papan | 68,000 |
| 2 | Dumai | 79,000 |

[5]) Lemigas, 1994

## a) Electrolysis

To split water by electrolysis means has been known long time a go. In this method cells similar to cell of battery in the car are used to produce hydrogen and oxygen from water. Each cell consists of two electrodes immersed in an electrolyte of water plus some chemicals that conduct electricity well, and is connected to a direct current (DC) electricity supply. About one per cent of worldwide hydrogen demand is produced electrolytically. Hydrogen production cost by this electrolytically is much higher than that fossil fuels.

In the development of electrolysis, the advanced concepts of electrolytic hydrogen production have been proposed to improve hydrogen production efficiency and to reach high hydrogen production density from view point of saving electricity. A solid polymer of water (SPE) and high-temperature electrolysis of steam (HTES) using ceramic electrolysis cell are representative of new advanced technologies. Figure 2 shows the structure of ceramic cell, developed in JAERI [6].

## b) Thermochemical cycle

In direct thermolysis, its need temperature around 2,500 to 3,000 °C to split water to hydrogen and oxygen. But using of thermochemical cycle means allow the operating temperatures lower than 1,000 °C.

Thousands of thermochemical cycles have been proposed in USA, Europe and Asia. But only few per cent of those cycles are continuously studied to bench-scale and pilot plant. Among these cycles which have a good promised to the future hydrogen production are sulfur family (IS cycle, Mark cycle) and bromine family (UT-3 cycle).

**IS Cycle:**

Iodine-sulfur cycle (IS-cycle) consist of three steps reactions as follow:

$$I_2 + SO_2 + 2H_2O = H_2SO_4 + 2HI \quad (5)$$
$$2HI = H_2 + I_2 \quad (6)$$
$$H_2SO_4 = H_2O + SO_2 + 0.5\ O_2 \quad (7)$$

· thickness of each layer : 0.1~0.25mm
· thickness of support tube : 3mm
· the same configuration and materials as the SOFC

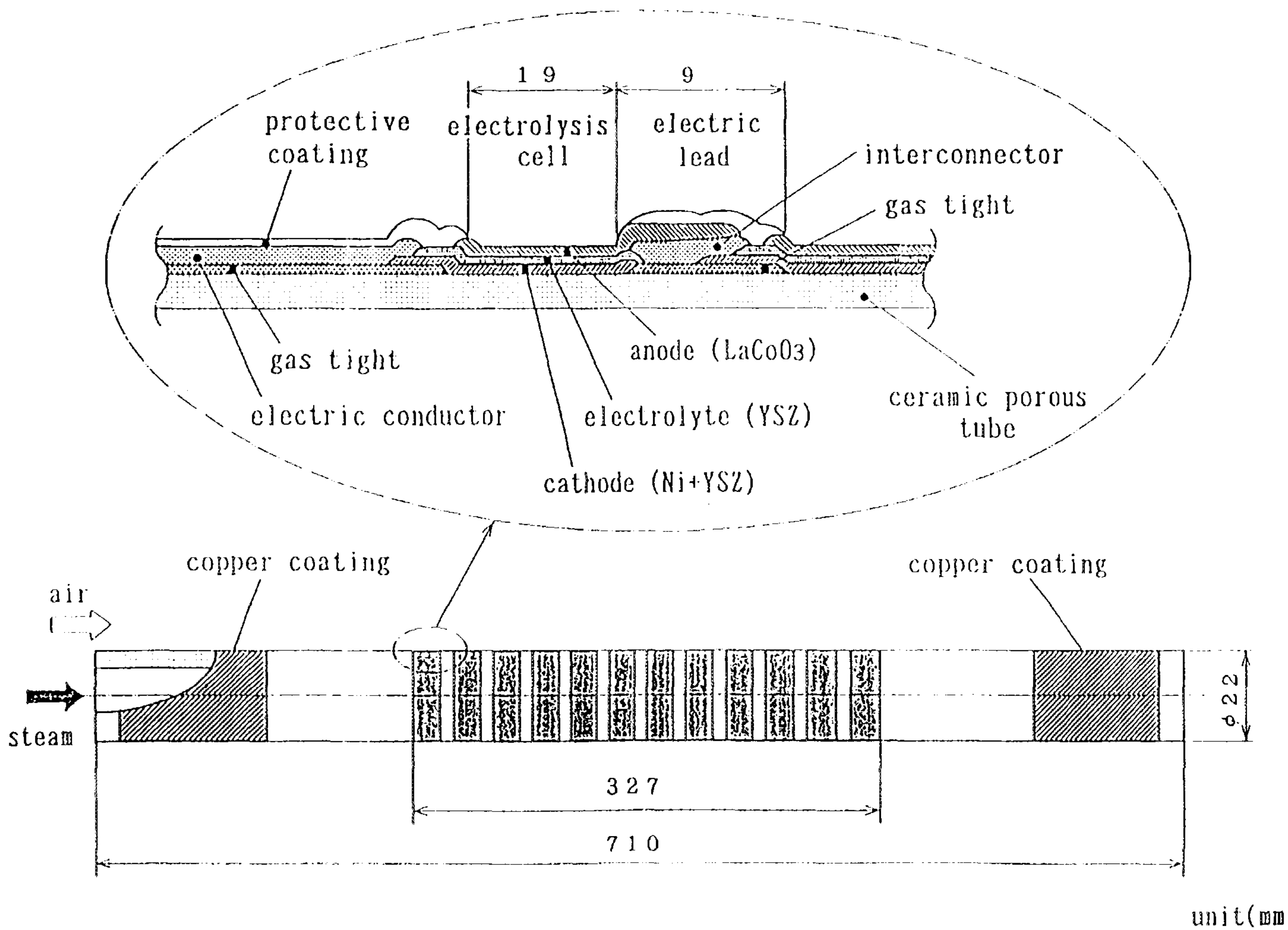


**Fig. 2 Electrolysis tube with 12 cells [6]**

IS cycle first proposed by General Atomic-USA. Since that KFA Julich-Germany and JAERI-Japan are continuously studying this cycle and successful operated at laboratory bench-scale plant with its total hydrogen production 16.4 liter. Figure 3 shows a simplified flow-sheet of the experimental apparatus which was designed to realized to the basic function of the process. The apparatus was designed to have the capacity Of 1-10 liter $H_2$/hour, is made of quartz, glass and Teflon.

**UT-3 Cycle:**

The third generation of Tokyo University cycle (UT-3 cycle) consists of fourth steps reactions as follow:

$$CaBr_2 + H_2O = CaO + 2HBr \quad (8)$$
$$CaO + Br_2 = CaBr_2 + 0.5O_2 \quad (9)$$
$$Fe_3O_4 + 8HBr = 3FeBr_2 + 4H_2O + Br_2 \quad (10)$$
$$3FeBr_2 + 4H_2O = Fe_3O_4 + H_2 \quad (11)$$

UT-3 cycle was proposed by Kameyama et al. (Japan) in 1978. Ten research groups and nine Universities have successful operated a UT-3 bench-scale (MASCOT) with the capacity of 3 liter/hour. Toyo Engineering under the contract with JAERI has finished the feasibility study of commercial UT-3 hydrogen production plant capacity 20,000 $Nm^3$/hour. Figure 4 shows the flowsheet of the UT-3 hydrogen plant. HTGR is considered as the heat source. Helium gas is assumed to be introduced to the UT-3 hydrogen plant at 850 °C and supplies the necessary heat for the reactions. The result shows that the thermal efficiency is 40% and hydrogen production cost is 42 yen/$Nm^3$, based on assumption of the cost of nuclear heat from HTGR is 0.91 Yen/MJ.

## 3. HYDROGEN MARKET ANALYSIS

Most of hydrogen produced are used in the chemical industry for the production of ammonia, plastics, foodstuffs, rubbers and pharmaceuticals, and also as a reducing agent in the metallurgical and scrap-metal recovery industry. Table 3 shows the number of the world's hydrogen consumption in various industries in 1970. This number will increase in the next future as industry growth sharply. Table 4 shows the number of hydrogen requirements in each types of industries.

### 3.1 Petrochemical industry

The oil refining industries in Indonesia are located in Sumatra, Kalimantan and Java as shown in Table 5. Refinery need for hydrogen in Indonesia are currently met by hydrogen plants in Table 2 and by recycling by-product hydrogen made in the industry. The capability to produce hydrogen by conventional steam reforming of natural gas does exist, but to minimize cost, by-product hydrogen is used whenever possible. In order for hydrogen supplementation of natural gas with hydrogen separation to penetrate the refinery hydrogen market in Indonesia, it must at very least, be competitive with steam reforming of natural gas.

### 3.2 Fertilizer industry

Ammonia production accounts for the largest industrial use of hydrogen in Indonesia, and is produced by the catalytic reaction of nitrogen and hydrogen at high temperature and pressure.

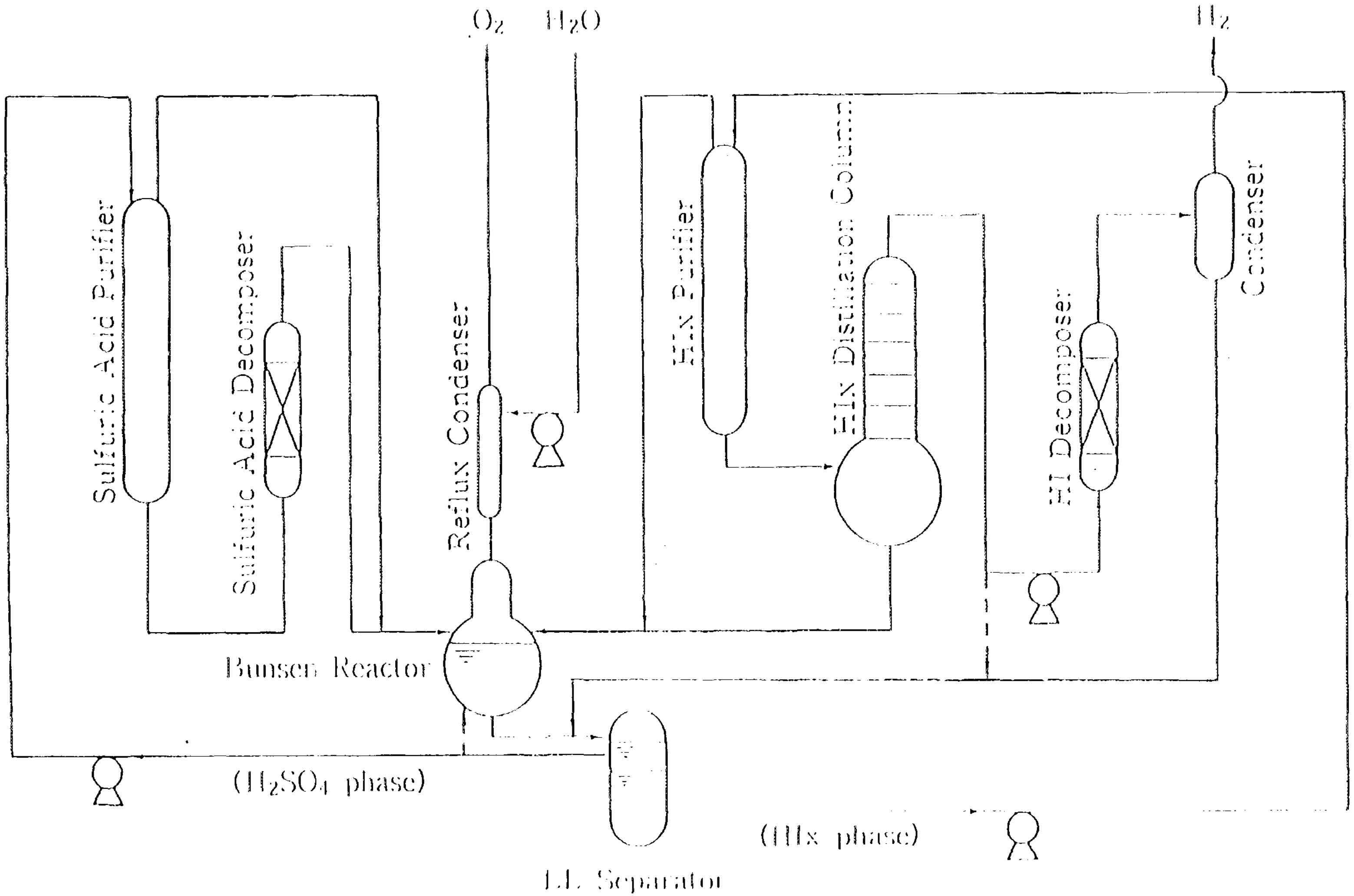


**Fig. 3 Schematic flowsheet of the laboratory scale demonstration apparatus [6]**

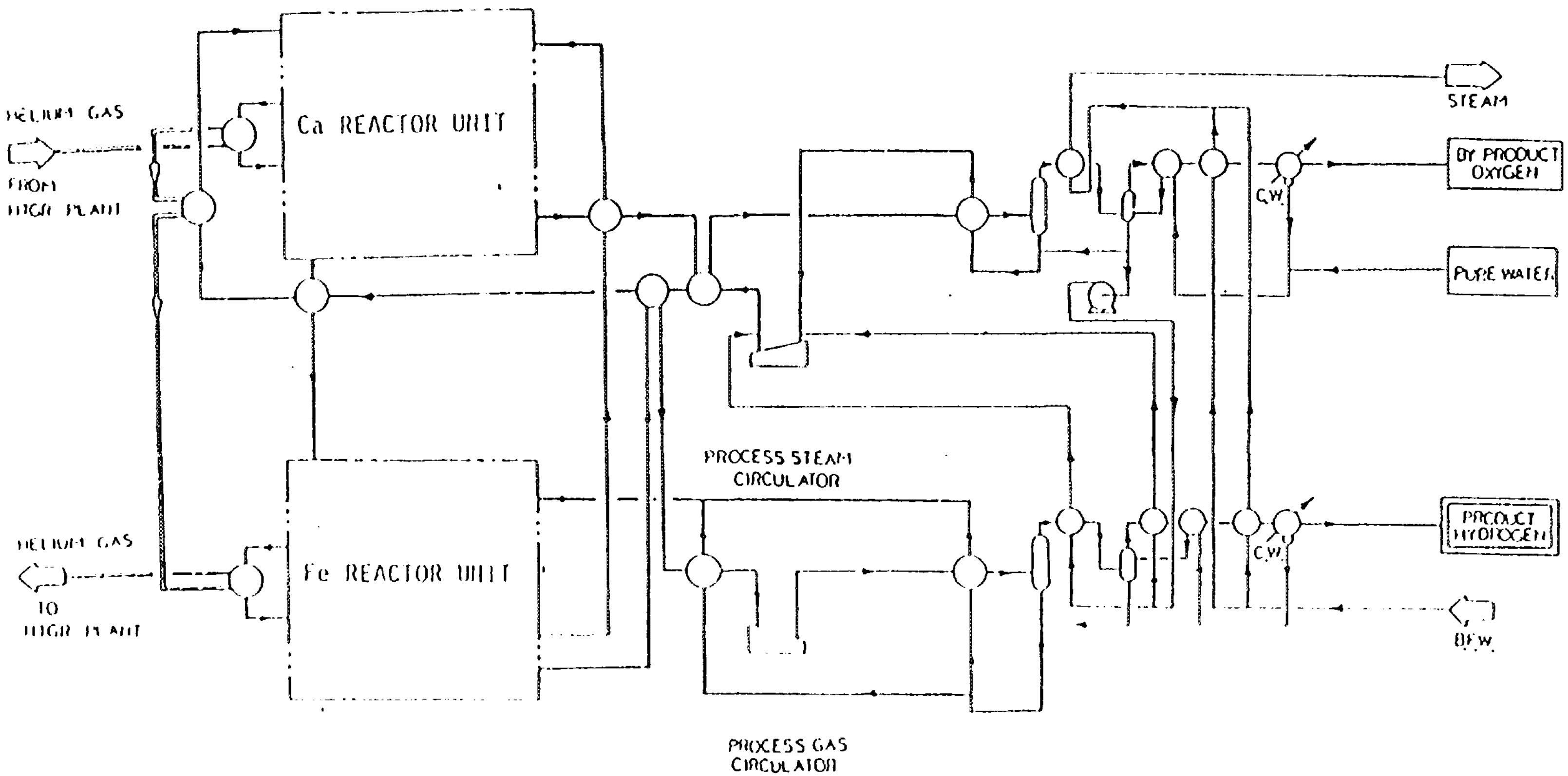


**Fig. 4 Flowsheet to UT-3 hydrogen plant [2,3]**

**Table 3 World consumption of hydrogen (1970)**

| Application | Consumption ($Gm^3$)[1] |
|---|---|
| Ammonia synthesis | 100 |
| Methanol synthesis | 25 |
| Synthesis of other chemicals | 10 |
| Hydrotreating desulphurization | 30 |
| Hydrocracking | 30 |
| Refinery fuel (low grade H2) | 10 |
| Total | 205 |

[1] Energy -Present and Future Options, Vol.3, John Wiley & Son Ltd., 1984

**Table 4 Typical industrial hydrogen requirements**

| Use | $H_2$ requirement per unit of product ($m^3$)[1] |
|---|---|
| Ammonia synthesis | 1950 - 2230/ton $NH_3$ |
| Methanol synthesis | 2.25/kg MeOH |
| Petroleum refining | 109/$m^3$ crude oil |
| Hydrotreating: | |
| naphta | 12/$m^3$ |
| coking distillates | 180/$m^3$ |
| Hydrocracking | 475 - 595/$m^3$ |
| Coal conversion to: | |
| liquid fuel | 1070 - 1250/$m^3$ |
| gaseous fuel | - 1560/($10^3$ SCM of synthesis gas) |
| Oil shale conversion to: | |
| liquid fuel | 230/$m^3$ of synthetic oil |
| gaseous fuel | 1200/($10^3$ SCM of synthetic gas) |
| Iron ore production | 560/(ton of iron) |
| Process heat | 82.4/GJ or 169/$10^3$ kg process steam |

[1] Energy -Present and Future Options, Vol.3, John Wiley & Son Ltd., 1984

**Table 5 Pertamina's oil refinery plant in Indonesia ( barrel/day)[1]**

| No | Location | Atm./Vac. Distill. | Hydro-cracking | Hydro-treating | Hydro-refining | Other-process |
|---|---|---|---|---|---|---|
| 1 | Balik papan | 348,800 | 51,200 | 20,000 | | 20,000 |
| 2 | Cilacap | 338200 | | 18100 | 13500 | 68400 |
| 3 | Dumai | 202200 | 47000 | 15400 | | 40700 |
| 4 | Musi | 158500 | | | | 18100 |
| 5 | P. Brandan | 4800 | | | | |
| 6 | S. Pakning | 46,100 | | | | |

[1] World Refinery survey, Business Review 1, April/1992

Then introduced to urea plants as shown in Table 6. It seems that the demand of urea fertilizer in Indonesia is continuously increased in the future as population and agriculture industries' growth as shown in Table 7. Hydrogen is manufactured by steam reforming of natural gas in essential all ammonia plant in Indonesia. Future ammonia plants in Indonesia might also employ coal gasification because of the high price of natural gas and concern over its long-term future supply. Beside ammonia and urea production (Figure 5), there is a sizable chemical industry located closed to oil and gas fields in Indonesia.

## 3.3 Steel industry

Hydrogen is currently used in steel industry to maintain a controlled reducing atmosphere for annealing and heat treating steel. Heat treating shops that purchase merchant hydrogen to meet their relatively small needs of roughly 1000 SCF/day are not particularly suitable for

**Table 6 Fertilizer plants in Indonesia**

| No | Company | Capacity (ton/year)[2] |
|---|---|---|
| 1 | PT. Aceh Fertilizer | 625,000 |
| 2 | PT.Pupuk Iskandar Muda | 570000 |
| 3 | PT. Pusri (I,II,II,IV) | 1,732,000 |
| 4 | PT.Pupuk Kujang | 570000 |
| 5 | PT. Pupuk Kaltim (I,II) | 1710000 |
| 6 | PT. Petrokimia Gresik | 460000 |

[2] Department of Industry RI, 1990

**Table 7 The projection urea fertilizer supply and demand in Indonesia (thousand ton/year)[1)]**

| No | Parameter | 1989 | 1994 | 1999 | 2004 |
|---|---|---|---|---|---|
| 1 | Production | 4,248 | 6,452 | 7,762 | 9,901 |
| 2 | Demand | 3184 | 4657 | 6087 | 7901 |

[1)] Department of Industry RI, 1990

hydrogen separation from supplemental natural gas because of their small, intermittent, and widely dispersed requirement for hydrogen. Plants that use hydrogen for annealing obtain it by purchasing merchant hydrogen and by on-site methane steam reforming.

A potential future uses of hydrogen in the steel industry is in the direct reduction of iron ore, a process that chemically reduces iron ore at temperatures well below its melting point. The reductants commonly used are carbon monoxide and hydrogen, which can be produced from fossil fuel. The direct reduction process produces a lowcost substitute for ferrous scrap and blast furnace iron at lower capital cost and reduced pollution than the blast furnace, which is conventional means of pig iron production. The blast furnace is extremely capital intensive, and in the current economic situation of the domestic steel industry, it is unlikely that new blast furnace will be built in the near future.

PT. Krakatau Steel is one of the largest steel industry in Indonesia. Its total steel production in various forms reached to 868,633 tons per year in last fiscal years. These number are projected to be 2.5 million tons per year in 1998 and 4 million tons per year in the year of 2000. Other steel industries are distributed in Java, Sumatra, Kalimantan etc. with its production capacity increase day by day.

## 3.4 Other future applications

Hydrogen plays a key role in the manufacture of many important materials and in many industrial processes. It provides a reducing atmosphere in the manufacture of float glass and the fabrication of electronic components. Hydrogen is used as raw material for hydrogen peroxide and methanol. Hydrogen is also used as a cooling medium in electric generators and large electric motors. It serves as fuel for space vehicle and is used to manufacture pharmaceuticals and hydrogenated fats and oils.

Depending on such factors as the size of the plant, the amount of hydrogen needed, daily fluctuation in this amount and the purity level required, the hydrogen for these smaller industrial uses can be produced on site by conventional steam reforming of methane, water electrolysis or thermochemical cycles, ammonia decomposition, or it can be purchased and delivered by pipeline, tank truck, or in compressed gas cylinders (merchant hydrogen). In the future hydrogen is projected to replace all the positions of fossil fuels in industrial process, transportation and household as shown in Table 8.

Source: Directorate general of oil and gas RI, 1990
Note : - Proven reserved 50% potential reserved
- Production: 80% proven reserved

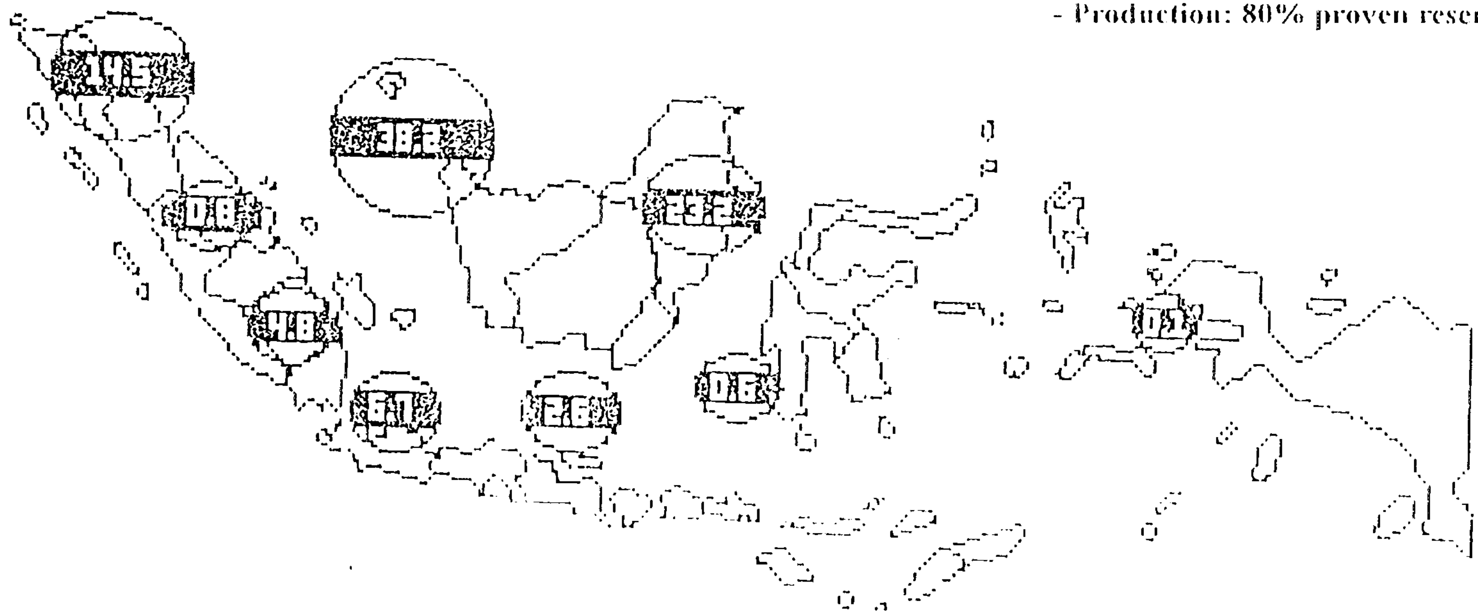

**Fig. 5 Potential map of natural gas reserved in Indonesia (TSCF) [11]**

**Table 8 Other future potential application of hydrogen**

| No | User | $H_2$ efficiency[1)] | Fossil efficiency (Comparison) |
|---|---|---|---|
| 1 | Converter machine<br>- Gas turbine<br>- Steam turbine<br>- Fuel cell | <br><br><br>40 - 85% | |
| 2 | Household<br>- Cooking<br>- Catalytic combustor<br>- Gas burner<br>- Space heating and cooling<br>- Lighting<br>- Water heating<br>- Refrigeration<br>- Home appliances and equipment | <br><br>>85%<br>70%<br><br><br>70%<br>long life,<br>low O-M | <br><br><br>60%<br><br><br>60% |
| 3 | Transportation<br>- Airplane, Aerospace<br>- Train<br>- Car<br>- Ship | <br><br><br><br>60% | <br><br><br>Petrol: 25% |

[1)] Solar hydrogen, the power to save the earth, Macdonald Optima, 1991

# 4. THE ROLE HYDROGEN IN THE FUTURE

## 4.1 Government policy

The demand of oil fuel increase year by year. During Last five-year plans the average of oil of demand is increased by 8.5% per year. Various diversification, conservation program have proposed by Government of Indonesia to reduce domestic consumption of oil fuel in the frame work of increasing or keeping oil export. Even Indonesia have some oil refining plants with the total capacity 1 million barrel per day or with the capacity of oil fuel 43.1 million kl/year. Still Indonesia has a deficit of 27.5 million barrel/year. This deficit will increase in the next future, and it is estimated that the deficit will be 44.3 million barrel/year in 1999 and 104 million barrel/year in 2004. A new plant should be build to meet with the deposit of oil. The large number hydrogen will be required for oil refinery plants in the near future. For oil and gas saving contributions, it is also considered to consume the produced hydrogen from other sources such as water.

To support the implementation of the Government policy of Indonesia in conservation and diversification of fossil energy, particularly in oil and natural gas, some efforts have been done such as audit energy program for saving energy (Table 9), Indonesia cleaner industrial production program, and adopted the ideas of foreign environmental regulations such as carbon tax, air ambient quality standard etc. One of the more extreme ideas is by introducing nuclear energy to industry processes to save fossil energy in Indonesia. Based on our experience a simple calculation was made to show how much the fossil fuel could be saved in industrial fields as shown in Table 10. It shows that around 117.7 BSCF of natural gas could be saved each year in urea ferlizer industry. A larger amount of natural gas and oil will be saved if this assumption may be applied to other industrial processes in Indonesia.

**Table 9 Potential energy saving of some industries in Indonesia**

| No | Industry | Potential saving[1] |
|---|---|---|
| 1 | Fertilizer | 25% |
| 2 | Textile | 10% |
| 3 | Cement | 10% |
| 4 | Ceramic | 15.5% |
| 5 | Iron/Steel | 20% |
| 6 | Tire | 10% |
| 7 | Tea | 18% |
| 8 | Manufacture | 25% |
| 9 | Glass | 20% |
| 10 | Building | 20% |

[1] Surveyed by PT. KONEBA

**Table 10 Potential energy saving of natural gas for heat process in fertilizer industry in Indonesia**

| No | Company | Capacity (ton/year) | Potential saving in heat process (BSCFY) [1] |
|---|---|---|---|
| 1 | PT. Aceh Fertilizer | 625,000 | 12.0 |
| 2 | PT. Pupuk Iskandar Muda | 570,000 | 10.9 |
| 3 | PT. Pusri (I,II,III,IV) | 1,732,000 | 33.3 |
| 4 | PT. Pupuk Kujang (I,II) | 570,000 | 10.9 |
| 5 | PT.Pupuk Kaltim (I,II) | 1,710,000 | 32.8 |
| 6 | PT. Petrokimia Gresik | 460,000 | 8.8 |
| | | Total | 117.7 |

[1] Based on estimation (Lemigas): to produced 1,500 ton of urea/day or 570,000 ton of urea/year is required 60 MMSCFD of natural gas (50% of this amount is used to consume in heating process)

## 4.2 Changing in our fuel system

In the future or post fossil era, two main candidates' energy sources are considered by the scientist and engineers. One is synthetic fossil fuels (syngas, SNG) and the other one is solar hydrogen energy system. Among the gas synthetics, SNG is the cheapest, while among the liquid synthetics, liquid hydrogen from hydro electric power is the cheapest as shown in Table 11, especially after adding with the cost of environmental damage to cost production of synthetic fuels.

Probably, the breaking away from polluting fossil fuels will not be carried out on the initiative of the Governments their selves, but the pressure should come from the all the peoples of the world. Even though hydrogen has been used as a fuel in NASA's and EUROPE's space program for many years, much more research needs to be carried out to bring this technology to a common market, to make it more affordable and usable. The areas of research still to be conducted are storage and leakage.

Demonstration projects have been run on hydrogen; cars, motorcycles, planes and coal-mining vehicle have all been run on clean hydrogen. To mass produce of these cars, motorcycles, planes etc. that use fossil fuels so that, instead, they operate on hydrogen, and to convert the pipeline infrastructure so that hydrogen can be transported, still need to spend hundreds millions of dollars per years. This is a trivial sum when we consider the cost of the awesome damage caused by pollution, that cost is estimated in hundreds of billions of dollars per year. As an example, Jakarta with its population eight million peoples has been paid about US $ 500 million per year for human health because of heavy air pollution in this area, according to World Bank surveyed.

**Table 11 Synthetic fuel production cost** ( gallon equivalent of petrol, 1990)[1)]

| No | | Production cost | | Effective cost | | Society cost |
|---|---|---|---|---|---|---|
| | | Gaseous | Liquid | Gaseous | Liquid | |
| 1 | $H_2$ from electric power | 1.42 | 1.78 | 1.05 | 1.31 | |
| 2 | $H_2$ from direct/ indirect solar | 1.91 | 2.38 | 1.41 | 1.75 | 1.37 |
| 3 | Synthetic natural gas from coal | 1.09 | 2.13 | 2.39 | 3.43 | 2.91 |

[1)] Solar hydrogen, the power to save the earth, Macdonald Optima, 1991

## 4.4 Time scale's shorting

Based on experiences show that from the point at which a scientist publishes an idea to the point that at which the product is available in the shops takes about 75 years. And from the point at which an engineer takes the scientist's idea and build a model and test it to see if it works, to the point at which it is available in the shops takes 50 years. But from the point at which a company takes a model and commercializes it to the point at which it is available in the shops only take about 15 years, maybe less.

However these timescales can change with the circumstances. In war time, everything gets done many times faster. An emergency spirit can unify nations like in the last war time. At present, that the same emergency spirit to develop and produce clean fuels such as hydrogen, to convert the factories using clean energy. And it need also same spirit to stop the war and allocate that fund to develop clean energy for human being.

## 4.5 Economic consideration

Some informations from economic point of view have been analyzed and evaluated. US federal Commission has calculated and evaluated the relative prices for delivered energy as shown in Table 12. It shows how, even when produced by electrolysis, hydrogen may be a cheaper synthetic fuel than electricity, at the point of consumption. Table 13 shows the summary of thermal efficiency and hydrogen production cost from water by electrolysis and thermochemical cycle compare to fossil fuel as raw material. Hydrogen production cost by thermochemical cycle is still higher than from natural gas.

**Table 12 Relative prices (US $ per GJ) for delivered energy (1970) [2)]**
**(US Federal Commission)**

| | Electricity | Natural gas | Electrolysis ($H_2$) |
|---|---|---|---|
| Production | 2.53 | 0.16 | 2.84 |
| Transmission | 0.58 | 0.19 | 0.49 |
| Distribution | 1.53 | 0.26 | 0.32 |
| Total | 4.64 | 0.61 | 3.65 |

2) Energy -Present and Future Options, Vol.3, John Wiley & Son Ltd., 1984

**Table 13 Some informations of thermochemical cycles and electrolysis**

| No | Information | Thermochemical | Electrolysis | Fossil (comparison) |
|---|---|---|---|---|
| 1 | Thermal efficiency[1)] | Mark cycle: 40-60%<br>IS cycle : >50%<br>UT-3 cycle: 42%<br>Others cycle: 41% | Elect. Eff. :<br>Conventional:<br>57 - 72 %<br>Advanced:<br>80% | |
| 2 | Production cost[2)] | UT-3 cycle:<br>46.4 yen / $Nm^3$ | | Natural gas:<br>32.6 Yen/$Nm^3$ |
| 3 | Investment cost | Is cycle:<br>US $1000/Nm3 | Conventional:<br>US$ 320/kg | |

1) Seminar on HTR technology and application II, 1995
2) Toyo Engineering, 1980

## 5. CONCLUSION REMARKS

1. Hydrogen could be produced from water by introduced of nuclear heat (HTGRs) to electrolysis and thermochemical cycle.

2. Hydrogen has a good prospect market in Indonesian industries such as petrochemical, fertilizer, steel and other chemicals industries.

3. Hydrogen which its high abundant raw material, clean and good recycle system will be competitive as one of the candidate energy source for the future energy system.

4. Hydrogen sound good, but it is more expensive then petroleum. The cost of environmental damage should be added to the cost of production of fossil fuels.

5. Possible to introduce HTGR to Indonesian industries processes to change the energy source from fossil to fissile, the way to reduce of using fossil fuel in the frame work of diversification and conservation energy program.

**REFERENCES**


1. Amir Rusli and Veronika Tuka, The aspects of hydrogen energy, BATAN-JAERI Seminar on HTR technology and application II, 1995
2. Amir Rusli and Ida Nuryatin Finahari, Thermochemical water-splitting for hydrogen production, BATAN-JAERI Seminar on HTR technology and application II, 1995
3. Amir Rusli, Hydrogen production by UT-3 thermochemical cycle, PhD thesis, TUAT, Tokyo, 1993.
4. Amir Rusli, Amos and Suharto, Prospek Energi Hidrogen "pasca" Migas (The prospect of hydrogen energy post oil and gas), to be submitted to Elektro Indonesia, 1995
5. Amir Rusli, Ign. Joko Irianto and Sarwo D.D., Peningkatan peranan energi listrik menyongsomg era globalisasi (The role of elctric energy in the next globalization era), Pre-Proceeding of Indonesian Electric Power Conference, 1995
6. First research coordination meeting on IAEA CRP-4 (HTTR heat application, Report, Tokaimura, Japan, 9-11 November 1993
7. John O'M. Bockris and T. N. Veziroglu, Solar Hydrogen Energy - The power to save the earth "fuel for ever", Macdonald Optima, 1991.
8. Tenth world hydrogen energy conference, Proceeding, Florida, 1994
9. Wahyudin, Hidrogen masa kini dan masa depan (Hydrogen for present and future), Pre-proceeding KNI-WEC, Jakarta, 1994
10. Energy - Present and Future Options, Vol. 2, John Willey & Son, 1984
11. Lemigas, Gas and Oil report, 1994