—Summary—

HYDROGEN MARKETS AND FUTURES FOR NUCLEAR POWER

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ABSTRACT

Changing crude oil supplies and requirements for liquid fuels (gasoline, jet fuel, etc.) are rapidly increasing the demand for hydrogen (H_2) by refineries and chemical plants. Within a decade, the energy that would be required to make this H_2 by thermo-chemical methods may exceed the energy output of all the nuclear power plants in the United States. This is independent of any future "H_2 economy" that uses fuel cells or distributed-power systems. If nuclear reactors can be developed to economically produce H_2, the traditional industrial market would be sufficient to support a major expansion of nuclear power. Hydrogen pipelines, the equivalent of the power grid, exist between refineries and merchant H_2 plants to allow deployment of large H_2 plants.

I. INTRODUCTION

As part of the effort to develop a Generation IV roadmap for the future of nuclear power, an examination of alternative uses for nuclear energy was made (Forsberg 2000). Hydrogen production was identified as a large and rapidly growing market.

II. GROWTH IN INDUSTRIAL H_2 DEMAND

World consumption of H_2 for the production of chemicals (e.g., CH_3OH and NH_3) and the refining of crude oil into transport fuels is growing rapidly. Hydrogen is added to heavy crude oils to (1) produce lighter fuels such as gasoline, (2) remove impurities such as sulfur, and (3) reduce the toxicity. As resources of high-quality light crude oils are exhausted, more H_2 is required to produce an equivalent amount of gasoline per barrel of lower-grade crude oil (Fig. 1). Whereas high-quality crude oils have an H_2-to-carbon ratio of 1.5 to 2 (similar to that for gasoline), heavy oils have a ratio as low as 0.8. Therefore, large quantities of H_2 are required to make gasoline from heavy crude oils.

Hydrogen is produced from natural gas (-5% of U.S. natural gas) and lower-value refinery streams. An economical outside source of H_2 would allow the lower-value refinery streams to be converted into gasoline rather than require their use for H_2 production. As a result, the output of liquid fuel per barrel of crude oil could significantly increase, thereby reducing crude oil imports. Economic nonfossil H_2 would (1) substantially reduce carbon dioxide emissions and (2) protect the domestic chemical and refinery industries from high natural gas prices. If the recent high prices of natural gas continue, parts of these industries may move offshore for lower-cost sources of natural gas to manufacture H_2.

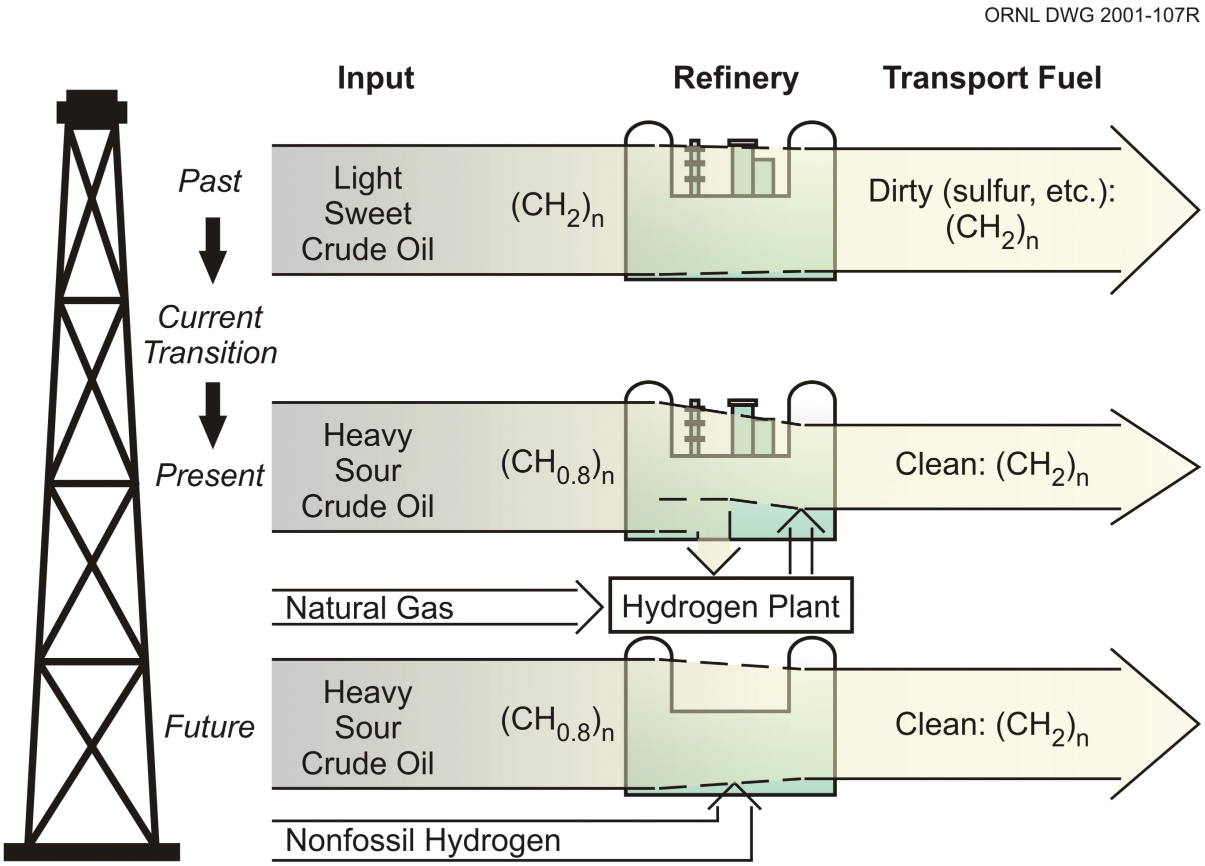

Fig. 1. The changing characteristics of available crude oil supplies are increasing the refinery demand for hydrogen.

The H_2 production capacity of the world's refineries is 3.26×10^8 m^3/d (1.15×10^{10} std ft^3/d), with a U.S. refinery hydrogen production capacity of 1.01×10^8 m^3/d (3.56×10^9 std ft^3/d) (Chang 2000). Industrial demand to produce chemicals and liquid fuels for the U.S. may increase by a factor of 4 such that by 2010 the energy value of the H_2 is 6×10^{18} J/year (Ogden 1999). Assuming a thermal-chemical process with 50% conversion of heat energy to H_2, the energy required for H_2 production would exceed the thermal energy output of all nuclear reactors in the United States.

Hydrogen has also been proposed as a future transport and distributed-power fuel. These applications would further increase the H_2 demand by an order of magnitude. Under such conditions, the energy required for H_2 production may exceed that required for production of electricity.

III. METHODS OF H_2 PRODUCTION

Hydrogen and electricity represent the only large potential markets for nuclear energy. Therefore, if the uses of nuclear power are to expand, reactors must be designed to efficiently produce H_2. Many direct thermo-chemical methods (heat plus water yields H_2 plus oxygen) are possible for producing H_2 (Brown 2000; IAEA 1999; Miyamoto 1998). High temperatures (750 to 1000EC) are required to ensure rapid chemical kinetics (small plant size with low capital costs) and high conversion efficiencies (-50% thermal energy converted to H_2).

Hydrogen production efficiency can be defined as the energy content of the H_2 divided by the energy expended to produce the H_2. Hydrogen production by electrolysis is efficient (-80%). However, when this percentage is combined with the electrical conversion efficiency (ranging from -34% in current LWRs to 50% for advanced systems), the overall efficiency would be in the range of 25 to 40%. The inefficiencies and capital-cost penalties suggest that thermo-chemical approaches will be significantly more economic.

Three reactor concepts have been identified that may produce the high temperatures required for H_2 production: (1) the high-temperature gas-cooled reactor (HTGR), (2) the Advanced High-Temperature Reactor (AHTR), and (3) the lead-cooled fast reactor. The AHTR is a molten-salt-cooled reactor that uses a fuel similar to that of the HTGR.

REFERENCES

Brown, C. L., J. F. Funk, and S. K. Showalter, July 2000. *High Efficiency Generation of Hydrogen Fuels Using Nuclear Power*, GA-A23451, General Atomics Corp., San Diego, California.

Chang, T, December 18, 2000. "Worldwide Refining Capacity," *Oil and Gas Journal*, pp. 56–120.

Forsberg, C. W. and K. L. Peddicord, July 2001. *Hydrogen Production as a Major Nuclear Energy Application*, Generation IV Nonclassical Technical Working Group.

IAEA, May 1999. *Hydrogen as an Energy Carrier and Its Production by Nuclear Power*, IAEA-TECDOC-1085, International Atomic Energy Agency, Vienna, Austria.

Miyamoto, Y., S. Shiozawa, M. Ogawa, N. Akina, S. Shimizu, K. Hada, Y. Inagaki, K. Onuki, T. Takeda, and T. Nishihara, 1998. "Overview of HTGR Heat Utilization System Development at JAERI," *Nuclear Heat Applications: Design Aspects and Operating Experience*, IAEA-TECDOC-1056, International Atomic Energy Agency, Vienna, Austria.

Ogden, J. M. 1999. "Prospects for Building a Hydrogen Energy Infrastructure," *Annu. Rev. Energy Environ.*, **24**, 227–279.