POTENTIAL APPLICATIONS OF HYDROGEN GENERATION FROM CHEAP FORMS OF ALUMINUM REACTING WITH WATER

by
Dr. Solomon Zaromb [1] and Dr. Joseph R. Stetter [2]

[1] Zaromb Research Corp., Burr Ridge, IL 60527, email address: zarombs@cs.com
[2] Professor of Chemistry, Illinois Institute of Technology

Abstract

Aluminum as a safe and compact means of energy storage and hydrogen generation is obtainable immediately from presently unutilized waste and in future years from an emissions-free process. Salvageable aluminum waste should be highly advantageous for stationary power backups, for electric motor boats, and for economizing fuel by injecting hydrogen into the intake manifold of internal combustion engines, but there is not enough of it at present for powering a sufficient number of electric automobiles to seriously impact global warming. This paper is therefore restricted to the above three immediately realizable applications, keeping in mind that it should eventually be possible to produce enough inexpensive aluminum without adding CO_2 to the atmosphere by restricting the power supplied to its production plants to carbon-free sources, sequestering plant emissions, and using an inert anode-wetted cathode process.

Introduction

Although more than 50 percent of America's aluminum is recycled, about “2 million tons of aluminum cans, containers and other types of packaging are thrown away each year” (1).

Besides uncollected aluminum cans and other packaging (foils, wrappings, and various containers), there are also large amounts of machine shop filings, and other scrap winding up in landfills instead of serving as fuel for backup power in homes, hospitals, and other vital facilities.

During the Katrina disaster, the disruption of cellular phone communications prevented many victims from even informing whatever helpers may have been available of their critical situation. Had the cellular communication towers been powered by a system that would be immune to flooding, many lives might have been saved.

Therefore, **our first application for hydrogen from aluminum waste is back-up power for homes, hospitals, and other indispensable facilities.**

Although formation of hydrogen by the reaction of aluminum with water has been known for more than sixty years (2), its utilization for the generation of heat and electricity from aluminum, especially from waste, was not proposed until some 30-40 years ago (3, 4). Nevertheless, among the various alternative energy sources currently under consideration, aluminum is rarely mentioned, probably because of wide disappointment with the intense and expensive attempts to develop an Al-air electric vehicle battery during the 1970's and 1980's (5, 6). Besides the problems encountered in those efforts (7), we found in our own work the overshadowing tendencies of:

a) the air cathodes in the Al-air system to get clogged by $Al(OH)_3$; and
b) an uncontrollable corrosion reaction to occur in the presence of some impurities.

The clogging problem disappears and corrosion is what we want when hydrogen is generated by dissolution of Al in alkaline solution according to the reaction:

$$2Al + 3H_2O \rightarrow 2Al(OH)_3 + 3H_2 \qquad [1]$$

yielding 1 g H_2 per 9 g Al + 9 g H_2O. The energy dissipated in Reaction 1 may be partly recovered by feeding the generated H_2 to a fuel cell. Assuming 100% current efficiency and a fuel cell output of 0.7 volt, the energy yield from Reaction 1 amounts to 2.1 kWh/kg of aluminum.[a] An obvious reason to consider aluminum and water for H_2 generation is the ease and safety with which these reagents can be transported, stored, and used.

The high energy density of aluminum and its non-flammability render it the material of choice for safely storing a large supply of energy within a modest volume. An 8-m^3 half-full bin could store 10,800 kg of aluminum in form of comminuted chips, pellets or granules, which could yield about 23,000 kWh when reacted with water so as to generate hydrogen for a fuel cell, enough to supply 100 kWh continuously for nearly 10 days. Since a system such as outlined in Fig. 1 could be built to withstand flooding, it could assure cellular phone communications throughout the duration of Katrina-like disasters with possible savings of many lives and maintenance of the functionality of backed up homes and facilities.

Although considerable progress has been made in recent years in developing commercialized Al-air batteries (8), we know of only one recent approach to the generation of hydrogen by our above Reaction 1, and that approach uses a not inexpensive alloy of aluminum and gallium (9). Similarly, the cost of the aluminum used in the recently reported batteries may adversely affect their competitiveness, especially for the motor vehicle applications for which they are mainly promoted.

Other attractive applications for the use of Al waste as per Reaction 1 are:

a. For electric boat propulsion; and
b. For injection of hydrogen into the intake manifold of an internal combustion engine (ICE).

The electric boat application is obviously highly attractive because the availability of plentiful water doubles the effective energy density of the power source. The injection of hydrogen into the ICE is discussed in a following section.

This paper is regrettably inapplicable to the propulsion of ground-based electric vehicles because the amount of aluminum presently wasted could only supply a small fraction of the potential

---

[a] 0.7 (volt) × 97,000 (coulombs/Faraday) × 1 (Faraday/9 g Al) ≈ 7,500 joules/g ≈ 7.5×10^6(joules/kg) / 3.6×10^6 (joules/kWh) ≈ 2.1 kWh/kg

demand for it. Conceivably, as the uses of aluminum waste become popularized, a preference for products packaged in aluminum rather than other metals, paper, plastics or glass may eventually result in major increases in disposable aluminum waste. It is also possible that major cost and energy savings may be achieved by a process using inert anodes and wetted cathodes for the production of aluminum [11 kWh/kg versus the current 15 kWh/kg] and this process may also be substantially free of emissions of greenhouse gases, especially carbon dioxide and fluorocarbons (10). A major obstacle to the actual construction and operation of inert anode smelting plants may be a concern as to whether the products of this process can meet the specifications of commercial grade aluminum. However, for hydrogen generation purposes, any impurities introduced into aluminum shot (grains, beads or pellets) from the inert anodes should not interfere in any way with the aluminum-water reaction. Therefore, the inert anode process may be fully functional at its present state of development for the production of aluminum beads or granules intended solely for hydrogen generation purposes. However, for the near term, we must restrict ourselves to those applications which appear to be immediately feasible.

Solutions

The hydrogen generator assembly of Fig. 1 includes a reaction chamber, wherein aluminum fed from a hopper is reacted with water to yield its hydroxide, hydrogen, and heat, with the rate of this process being automatically regulated by a servo-mechanism which adjusts the aluminum content within the chamber according to hydrogen demand. The aqueous solution is usually strongly acidic or strongly alkaline, but alkaline electrolytes containing 3 to 10 moles/liter of NaOH or KOH are preferred. The heat generated in the chamber may be dissipated by external heat fins or carried away by a circulating fluid and used for space heating or other applications. **The aluminum hydroxide reaction product is removed from the system and may be shipped for substantial refunds to producers of fresh aluminum or "of aluminum chemicals**, such as aluminum sulfide, sodium aluminate, aluminum fluoride, and aluminum chloride hexahydrate… petroleum catalysts, plastic and rubber goods, paper, glass and vitreous enamel, adhesives, varnishes, and toothpastes" (11).

To provide a failsafe back-up power system, the assembly is preferably sealed and made of rugged materials to render it resistant to flooding, fire, and other natural or manmade disasters. Besides being contained within a water-proof enclosure for the critical components of the system and its external wiring, the fuel cell of Fig. 1 should be placed as high as practicable with its air intake shielded from water droplets by a water-repelling porous Teflon filter. As a precaution against the flood level reaching so high as to obstruct air from passing through that filter, a compressed air or oxygen tank could be set up within the shielded enclosure to provide the needed oxygen for the duration of the obstruction.

Since back-up power is usually needed only in cases of electricity failures or other special circumstances, the aluminum waste that is to be fed to the hopper of Fig. 1 can be accumulated gradually by its users dropping it into a storage unit each time they would otherwise have disposed of it into a garbage bin. This would not only provide a cost-free and safe fuel, but could also yield some revenue from sales of the hydroxide product to aluminum chemicals producers. Since the amount of hydroxide generated from back-up power can not be expected to flood the chemicals market, its refund value may be substantial.

In Fig. 2, the hydrogen is fed to the intake manifold of an ICE, thus replacing a commercially available hydrogen fuel injection (HFI) system which generates hydrogen by electrolysis of water, such as those offered by the CHEC (Canadian Hydrogen Energy Company, LTD), or by the Canadian Eagle Research Company's HyZor On-Board Electrolyzer. Based on data provided for one commercial HFI system, we estimate that at least 7 gallons of combustible fuel (gasoline, Diesel, propane, natural gas, or fuel blends) could be saved from the injection of hydrogen generated by 1 kg of aluminum over a vehicle travel distance of about 2,000 km. While this could be obtained from presently wasted aluminum for about 30% of all household vehicles, the ample supply of more expensive aluminum could still yield a seven-fold return for all vehicle owners even at a price of $3/kg.

The injection of aluminum-derived hydrogen into the intake manifold of an ICE can be effectuated and controlled in the same way as is practiced with presently offered HFI systems whose hydrogen is derived from water electrolysis. The advantage of the aluminum-derived hydrogen is that its generation does not consume electrical power if the aluminum is obtained from waste.

In Figs. 1 and 2, disposable aluminum products are first ground down or cut up by a suitable cutting, grinding or other comminuting device (not shown) into particles sufficiently small to be attacked by an aqueous alkaline electrolyte in their reactor. Apparatus for grinding or cutting up aluminum objects may include a lathe, milling machine, grinder, and/or a guillotine-type device, or a suitable combination of the operating principles of one or more such devices, all of which are well known to persons skilled in the mechanical arts. Alternatively, some of the newest processes for producing inexpensive aluminum may eventually be adapted to yield aluminum in form of small particles, also called "aluminum shot".

Each of the three above-outlined applications appears to be within the present state of the art and its realization may require mainly financial investments for development work including detailed design and construction of a working prototype, thorough testing and evaluation of the first prototype, and implementation of any needed corrections and improvements, followed by large-quantity production and commercialization.

Conclusions

In summary, we presented three potentially advantageous uses of hydrogen generated from aluminum waste. These appear to be immediately realizable within the present state of the art making use primarily of inexpensive aluminum from presently unsalvaged waste. Each of these will result in significant energy savings at little or no cost to their users and none of them needs to add any direct or indirect burden to global warming.

Note

The disclosures of this White Paper are covered by a pending patent.

References

1. Anonymous, Aluminum Recycling, DRLP FACT SHEETS, Ohio Department of Natural Resources, Columbus, Ohio (2005)
2. W. H. Latimer and J. H. Hildebrand, *Reference Book of Inorganic Chemistry*, pp. 90-93 and 474-478, Macmillan Company, New York (1940)
3. I. E. Smith, "Hydrogen generation by means of the aluminum/water reaction," *J. Hydronautics*, **6**(2):106-109 (1972)
4. S. Zaromb, C. N. Cochran, and R. M. Mazgaj, "Aluminum-Consuming Fluidized-Bed Anodes," *J. Electrochem. Soc.*, **137**, 1851-1856 (1990)
5. J. F. Cooper, Weight and volume estimates for aluminum-air batteries designed for electric vehicle applications. Lawrence Livermore National Lab, UCRL-83881 (1980)
6. J. F. Cooper, K.A. Kraftick and B.J, McKinley, Proc. 18th Intersoc. Energy Convers. Eng. Conf., **4**:1628-1634 (1983)
7. E. J. Rudd and S. Lott, The development of aluminum-air batteries for application in electric vehicles. Final Report, SAND91-7066, Sandia National Labs. **(**1990)
8. W. H. Hunt, Jr., "Technology Insights: Aluminum Air Fuel Cell Becoming Commercially Viable," The Aluminum Association, **2008**
9. J. Woodall, as reported in *Science Daily,* "New Process Generates Hydrogen From Aluminum Alloy To Run Engines, Fuel Cells", Purdue University, May 18, 2007
10. N. Margolis and J. Eisenhauer, "Inert Anode Roadmap: A Framework for Technology Development." Document prepared for the Aluminum Association and the U.S. Department of Energy, Office of Industrial Technology, Columbia, MD (1998)
11. K. R. Van Horn, P. R. Bridenbaugh, and J. T. Staley, *in* Aluminum Processing: Smelting, *Encyclopædia Britannica*. Retrieved October 29, 2009, from Encyclopædia Britannica Online: http://www.britannica.com/EBchecked/topic/18071/aluminum-processing/81513/Smelting#ref623408

Fig. 1. Generation of Hydrogen from Aluminum Waste

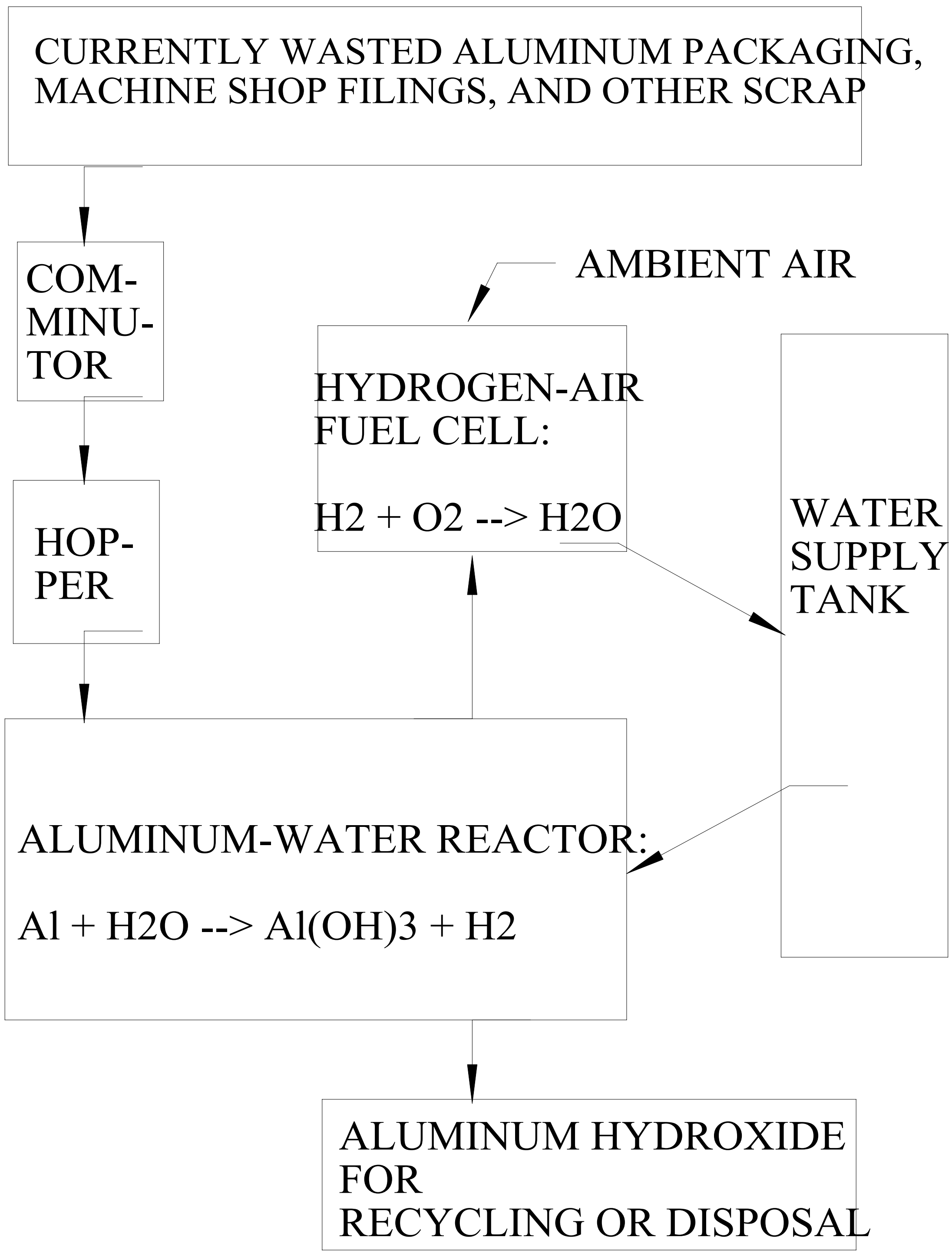

Fig. 2. Injection of Generated Hydrogen into Intake Manifold of Internal Combustion Engine