Waste-to-Hydrogen: Innovative Cartridge System using Recovered Aluminum from Waste Materials

N. Mizuki, A. Maruta

***Abstract*—**Authors have developed the multipurpose hydrogen generation cartridge using recovered aluminum from aluminum-containing waste materials. This cartridge contains recovered aluminum and reactants, and with small fuel cell the generated electricity is used for electricity demands at small residential. This system offers advantage of sustainability of energy and reduction of daily electricity cost, because the system is using waste, which causes some social costs.

***Keywords*—**hydrogen, fuel cell, aluminum, waste

I. Introduction

Aluminum is one of common materials in our society. However, aluminum-refining process is energy-consuming, and its price is unstable due to the increasing demand from emerging countries. Therefore, aluminum should be recycled as much as possible, energy-wise and material flow-wise.

One of typical application of aluminum is aluminum-coated packaging materials (e.g. snack packages, tablet-like drugs), and nearly 150,000 ton/year of aluminum is used for this application in Japan (Fig. 1).

Fig. 1 Aluminum-coated packaging materials

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Today, these aluminum-coated packaging wastes are simply burned and buried (one-way material flow), and such aluminum is barely recycled due to its low melting point (660 C) and its thinness.

If we recover such aluminum from the wastes, it may reduce the production volume of new aluminum, and we can reduce the energy that is required for the aluminum production from bauxite. Also, if such recovered aluminum is used for hydrogen production and generation of electricity, we can also cut the fossil energy demand.

For that purpose, the authors and partners are currently working on R&D on Waste-to-Hydrogen system, by developing the innovative "hydrogen-on-demand" cartridge. The overall system contains waste collection, dry distillation process, hydrogen generation cartridge, and electricity for home application (Fig. 2).

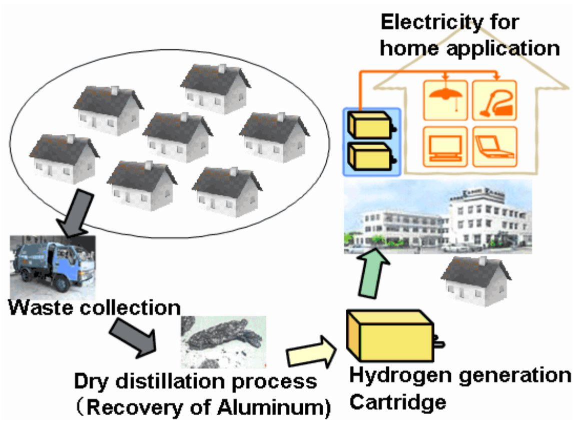

Fig. 2 Concept of "Waste-to-Hydrogen system" for home application

II. Waste Collection

Our investigation shows that these aluminum-coated packaging wastes account for one tenth of household burnable wastes in Japan.

Also, such aluminum-coated packaging wastes are produced from packaging factories (e.g. snacks, drugs, and drinks) as the industrial wastes.

Therefore, we may obtain the aluminum-coated wastes from the household as well as from the packaging factories (Fig. 3).

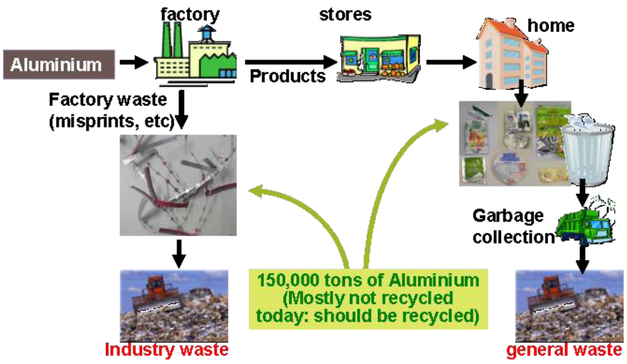

Fig. 3 Aluminum coating wastes from household and factory

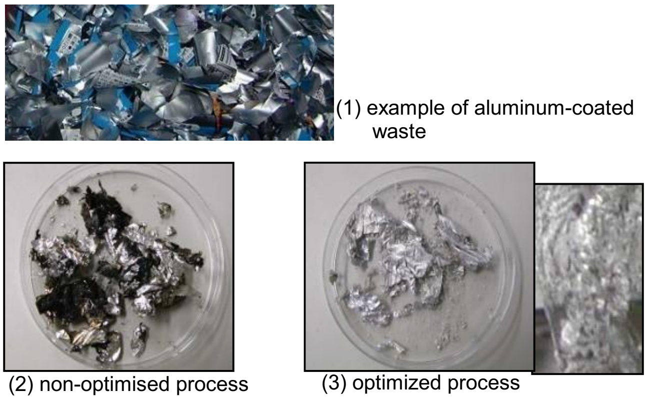

Fig. 5 Recovered aluminum from the dry distillation process

III. Dry Distillation Process

With partner company, Diamond Engineering Co. Ltd. (Uozu, Japan), the authors have developed special dry distillation process to recover aluminum from such waists using the prototype dry distillation reactor (Fig. 4).

Our investigation reveals that the optimum temperature is around 450-600 C. By this temperature, most of packaging materials (paper, plastics, and resin) are gasified. The Authors have further optimized the process by using generated gases as the fuel for dry distillation, so that virtually there is no energy input (net) for the process.

Size(mm):
1000 W x 4900 L x 2100 H
Capacity
50 kg/h (design)
Temp:
450-700 C (by hot air)
Rotating rate:
2-8 rpm

Fig. 4 Prototype dry distillation reactor

Fig 5 shows the recovered aluminum examples; the left sample contains carbon due to the non-optimized process, and the right one is recovered by the optimized process. The purity of the aluminum recovered by the optimized process around 95-98 %, chemically (evaluated by volumetric determination). Recovered aluminum is also highly porous, and it shows high reactivity.

The optimization requires the control of distillation temperature, oxygen concentration, and process time. These conditions depend on the conditions of wastes as well as packaging materials. Some examples require second distillation process to illuminate carbons.

The outlet gases are mainly hydrogen and carbon monoxide, which are all burnable gases and can be used as the heat source for the distillation reactor. By using the outlet gases, we can also minimize the energy for the distillation process.

One issue upon the distillation process is that some packaging materials, such as PVC, contain chlorine, which becomes dioxin during the distillation process, because of the low process temperature. Usually commercial incinerators burn the waste at higher temperature (800 C) to prevent the forming of dioxin, whereas our distillation process is around 600 C. Therefore, the distillation reactor requires other measure to illuminate dioxin, such as chemical trap at the gas outlet.

If we process plastic-based aluminum-covered waste materials, we can obtain recovered aluminum, burnable outlet gases as well as residual oil inside the reactor. The residual oil, which has the similar heat quantity as heavy oil, is also usable for heating the distillation reactor.

IV. Hydrogen Generation Cartridge System

Recovered aluminum cannot be used as the secondary bare aluminum, because of its thinness. (the commercial aluminum recycle companies use melting process, where thin aluminum slices are soon oxidized and cannot be refined.)

In order to use recovered aluminum, the authors and our research team have been working on the development of hydrogen generation cartridge by using the reaction (1):

$$Al + NaOH + 3H_2O \rightarrow NaAl(OH)_4 + 1.5\ H_2 \qquad (1)$$

(DH= -415.5kJ/mol)

This reaction can be simply controlled by the rate of dropping of NaOH solution onto recovered aluminum powder. From our investigation, the concentration should be around 20-30% to promote the reaction.

Our prototype hydrogen generation cartridge is rather large, and currently we are working on the second prototype (Fig 6). This cartridge is designed to operate at ambient temperature and pressure.

With this reaction, aluminum is converted to sodium aluminate ($NaAl(OH)_4$), which can be used for water industry (coagulant of water softening system), for paper industry (sizing agent), and for alumina production. Therefore, the byproduct is also industrially valuable.

The sysytem is using NaOH as the key agent to geenrate hydrogen, but it is also considered dangerous material. Therefore, the cartrige is designed to be an alsmot closed system, and only hydrogen can be flowed from the cartritge.

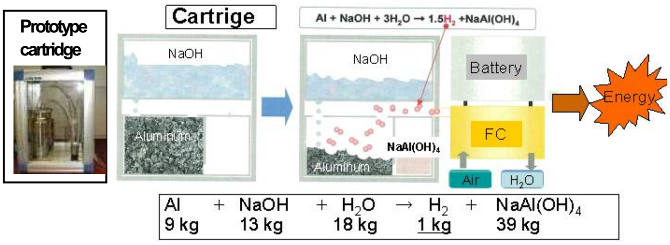

Fig. 6 Concept of hydrogen generation cartridge

Fig 7 shows the overall material flow of aluminum. Currently nearly 2 mil tons of aluminum (as aluminum-coated packaging waste) is simply burned and buried (conventional "burn and burry" process).

We propose that such aluminum can be collected and recovered by dry distillation process, and be used for hydrogen generation ("recover for hydrogen" process). Sodium aluminate, by-product, can also be used as the industrial material, so that recovered aluminum can be returned into the aluminum material flow. Therefore, CO_2 emission and energy consumption at aluminum production can be cancelled.

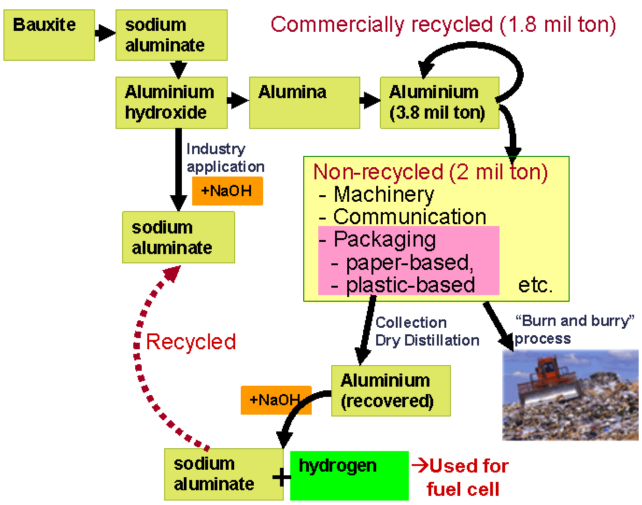

Fig. 7 Aluminum material flow

V. Evaluations of CO_2 and Energy Balance

Using this cartridge, theoretically 9 kg of aluminum (recovered from the aluminum-covered packaging waste) can generate 1 kg of hydrogen, whose energy content is 120 MJ (= 33.3 kWh). If the generated hydrogen (1 kg) is used at a fuel cell (assuming that fuel cell's energy efficiency is 30%), it generates the energy of 400 MJ. At Japanese grid mix, 1 kg of H_2 generated saves about 5kg of CO_2 from the power plants. Therefore, at the overall process, CO_2 emission is 10 kg, and energy gain is 145 MJ (Table 1).

TABLE I

Overall CO_2 / Energy Balance

Per 1 kg of H_2 generated	Production		Application		Overall balance
	Al (9 kg)	NaOH (13 kg)	$NaAl(OH)_4$ (39 kg, reused)	H_2 (1 kg) @30%	
CO2	9 kg (emitted)	15kg (emitted)	9kg (saved)	5 kg (saved)	10 kg (emitted)
Energy	168 MJ (used)	255 MJ (used)	168 MJ (saved)	400 MJ (generated)	145 MJ (used)

We have also compared the social cost and benefits for (A) conventional "burn and bury" process, and (B) "recover for hydrogen" and hydrogen generation cartridge (Table II). It is revealed that our (B) process potentially provides social benefits of 51-63 USD/ton-waste, whereas conventional (A) process requires social costs of 500 USD/ton-waste.

TABLE II

Social Costs / Benefits (With 1 tons of Al-coated waste)

(A) conventional "burn and bury" process	**→ Social cost: 500 USD/ ton-waste**
(B) "recover for hydrogen"	- 200～250 kg of Aluminum can be recovered. - 22-27 kg of Hydrogen can be generated (consumes 290-360 kg of NaOH: 58-72 USD). - 870～1100 kg of sodium aluminate can be produced as a by-product. It can be sold at 0.1 UDS/kg. (87-110 USD) **→Social benefits: 29 - 38 USD/ ton-waste** - 22-27 kg of Hydrogen produces 730- 890 kWh of energy (at 30 % efficiency, it will be 220 - 270 kWh). It can avoid the electricity cost of 22-27 USD (@10 cents / kWh). **→Social benefits: 51 - 63 USD/ ton-waste**

VI. Demonstrations

The cartridge can be cost-competitive, because this system does not require any high pressure system and metal hydrides. The cartridge can be used for home applications (lighting, electric appliances, CHP, UPS, and backup power), as well as mobile applications.

The Authors concluded the R&D contract with Japanese Government for the next three years, and also have organized "Hokuriku Green Energy Society", the public-private partnership at Hokuriku district of Japan. The Society conducted the public lighting demonstration on December, 2009; the small prototype cartridge (Fig 8).

Fig. 8 Demonstrations using the system
(LED lighting, December 2009)

VII. Conclusion

Authors are working on an innovative Aluminum-hydrogen system, using Aluminum from the wastes. The system is innovative and unique process which converts negative value (waste) into positive value (energy). We believe our system can be beneficial to any places in the world.

Acknowledgment

Author thanks the R&D funding support from the Ministry of Environment, Japan. Also Authors thank our R&D partners; Nihon Tetra Pak, Astellas Toyama, Asahi Printing, Ryohshin, Diamond Engineering, Nachi-fujikoshi, University of Toyama, Nakashima, and Technova Inc.

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