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研究課題名（和文）Local Initiative Hydrogen Production by Aluminum Waste-Hot Spring Water Reaction

研究課題名（英文）Local Initiative Hydrogen Production by Aluminum Waste-Hot Spring Water Reaction

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研究成果の概要（和文）：本研究は、地域規模の水素エネルギー構想のために、酸性温泉を介した直接的な地熱利用を探求する学際的アプローチを用いている。本研究は、酸化アルミニウム層を破壊するために、特定のpHと温度条件下でアルミニウム-水低熱水反応を利用することの有効性と費用対効果を実証した。さらに、本研究は、実験室および現場での実験において、酸性温泉を用いた廃棄物（アルミニウムドロスおよび切削くず）の利用の可能性を検証した。環境評価により、アルミニウム廃棄物から排出される二酸化炭素は、アルミニウムを主成分とする水素やガソリン燃料よりも少ないことが明らかになった。

研究成果の学術的意義や社会的意義
この研究は、温泉とアルミニウム廃棄物を利用してグリーン水素を製造するパイオニアである。複雑な処理やメカニズムを必要としない、グリーン水素製造の新たな選択肢を提供するものである。グリーン水素製造であることに加え、提案された方法は、廃棄物管理戦略、直接的な地熱利用、酸性温泉の中和といった利点がある。

研究成果の概要（英文）：This study uses a multidisciplinary approach to explore direct geothermal use via acidic thermal springs for local-scale hydrogen energy initiatives. The study demonstrates the effectiveness and cost-efficiency of utilizing the aluminum-water low hydrothermal reaction under specific pH and temperature conditions to disrupt the aluminum oxide layer. Furthermore, the study validates the potential use of waste materials (aluminum dross and cutting chips) with acidic hot springs at the laboratory and onsite experiments. Environmental assessment reveals lower carbon dioxide emissions from aluminum waste than primary aluminum-based hydrogen and gasoline fuels.

研究分野：Environmental studies

キーワード：Hydrogen production　Direct geothermal use　Alumnium waste　Acidic hot spring　Life cycle assessment

１．研究開始当初の背景

In response to escalating global energy demand and mounting sustainability challenges, there is a pressing need for scalable, cost-effective, and low-carbon alternatives to fossil fuels. Hydrogen, with its attributes of clean combustion, high energy density, and versatility, emerges as a promising energy carrier, but its conventional production from fossil fuels hampers its environmental friendliness. A sustainable method for hydrogen production using renewable, locally available, and cost-effective resources, focusing on the low hydrothermal reaction between aluminum and water, is studied. In this context, aluminum waste materials were suggested as substitutes for primary aluminum, and acidic hot spring water was favored over pure water. This approach offered a more environmentally friendly alternative by leveraging the unique properties of acidic hot spring water and repurposing aluminum waste materials (e.g., aluminum dross and cutting chips) without additional processing. The feasibility and effectiveness of this method were investigated through laboratory and onsite experimentation, complemented by environmental and techno-economic assessments.

２．研究の目的

In this research, we proposed a renewable method for hydrogen production to meet its rapidly growing future demand, focusing on environmental sustainability and cost-effectiveness. This involved utilizing naturally occurring acidic hot spring resources and aluminum wastes through a low hydrothermal aluminum-water reaction (below 100°C). To achieve this objective, several key issues needed to be addressed: (1) the feasibility and reaction mechanism of the method is investigated at a fundamental level, and (2) testing the potential design of the hydrogen production plant through onsite experiments (Tamagawa and Zao spring sites). Furthermore, the practical application of the method was evaluated by conducting a life cycle assessment to assess its environmental impacts, and a techno-economic assessment was used to determine its cost-effectiveness, considering the materials and processes involved.

３．研究の方法

This study began with a fundamental investigation into renewable hydrogen production through the aluminum-water low hydrothermal reaction. We explored hydrogen generation from the reaction of pure aluminum powder with water, encompassing a temperature range of 40-100°C and extreme pH conditions (1-2 for acidity adjusted by HCl and H_2SO_4 and 11-13.5 for alkalinity adjusted by NaOH) without additional treatments. By comparing reactions across various pH levels and temperatures, we elucidated the reaction mechanism for each solution. Moreover, we obtained valuable insights into reaction kinetics from the hydrogen production results, facilitating the development of a predictive model for hydrogen production. Next, we assessed the feasibility of our proposed approach by reacting aluminum wastes (specifically dross and cutting chips) and acidic hot springs at pH 1 and temperatures up to 100°C. This evaluation was conducted through both laboratory and onsite experiments. The onsite experiments conducted at Tamagawa and Zao Springs aimed to demonstrate our method's practical application.

Furthermore, we conducted an environmental assessment encompassing carbon dioxide emissions and energy consumption associated with the proposed hydrogen system. This assessment considered all pertinent aspects of materials and processes, including resources, transportation, production, distribution, utilization, potential contributions, and emissions associated with hydrogen fuel. A techno-economic assessment was considered to appraise the cost-effectiveness of this method, taking into account the same critical factors.

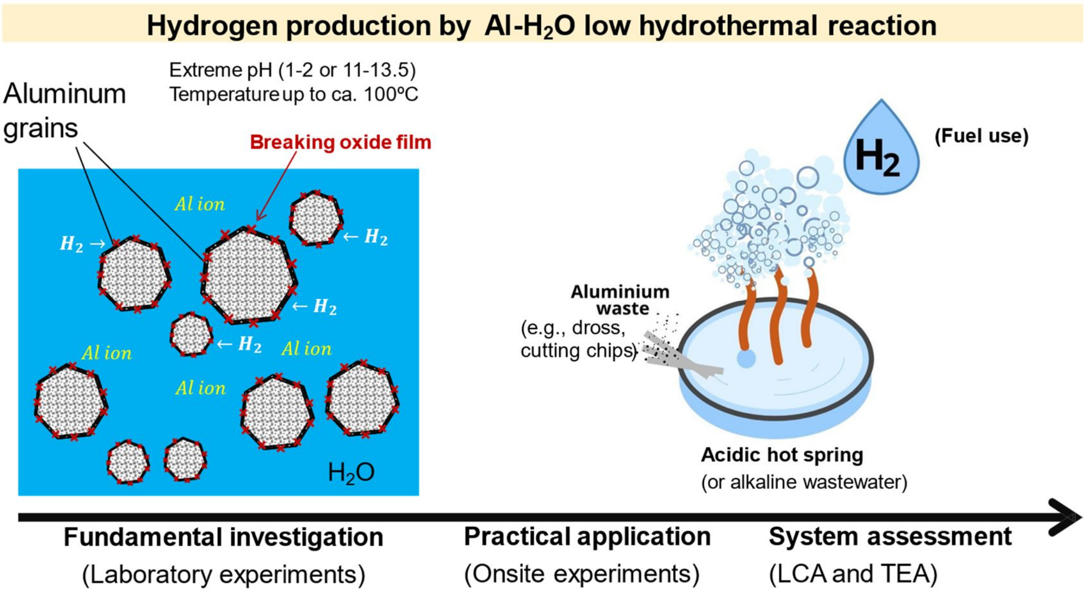

Figure 1. Research conception of the aluminum-water low hydrothermal reaction for hydrogen production.

４．研究成果

The study found that strong acidity or alkalinity and elevated temperature disrupted the oxide layer on aluminum surfaces, enhancing its reactivity with water to release hydrogen. The predictive model aligned well with on-site measurements at the Tamagawa and Zao hot springs (Alviani et al., 2019). The study also demonstrated the potential of utilizing aluminum waste materials and acidic hot springs for hydrogen production through the aluminum-water hydrothermal reaction. The hydrogen production rate was notably temperature-dependent and influenced by aluminum content and specific surface area. Due to their higher aluminum content, aluminum cutting chips exhibited a higher yield than aluminum dross. Onsite experiments with aluminum cutting chips and an acidic hot spring yielded approximately 3 mol of hydrogen per kg of aluminum chips within 6.75 hours (Figure 2. (right)).

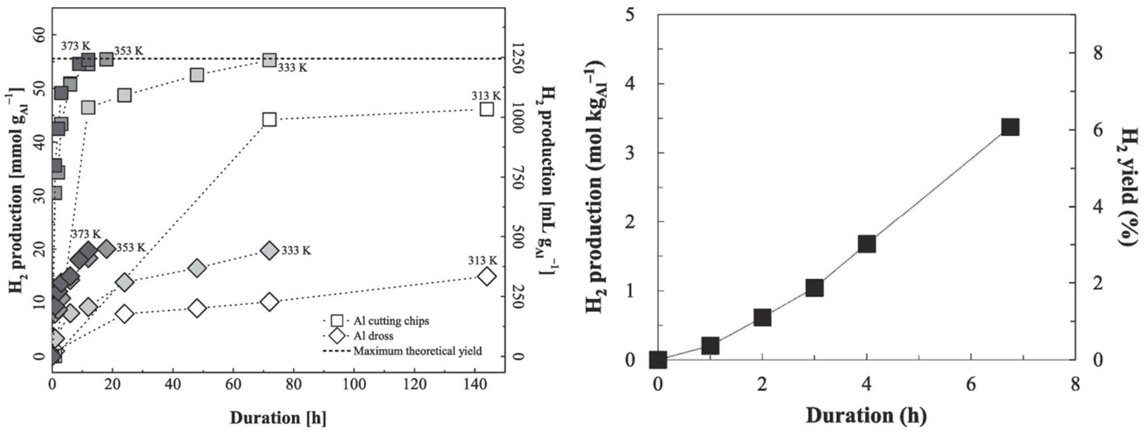

Figure 2. (left) Hydrogen production from aluminum cutting chips and dross in acidic hot springs. (right) On-site hydrogen production from aluminum cutting chips and acidic Tamagawa spring.

The environmental assessment revealed that utilizing aluminum waste materials and acidic hot spring water is a more environmentally favorable approach compared to primary aluminum-based hydrogen fuel and gasoline for the same usable energy output, which was advantaged from a carbon dioxide reduction of the neutralization process (Figure 3; Alviani et al., 2021). This study highlights hydrogen production as a promising means of utilizing aluminum waste and advancing direct geothermal use. From techno-economic results, the proposed method for hydrogen fuel use can gradually compete with current hydrogen retail and target prices considering environmental concerns, technological advancements and maturity, and subsidy schemes.

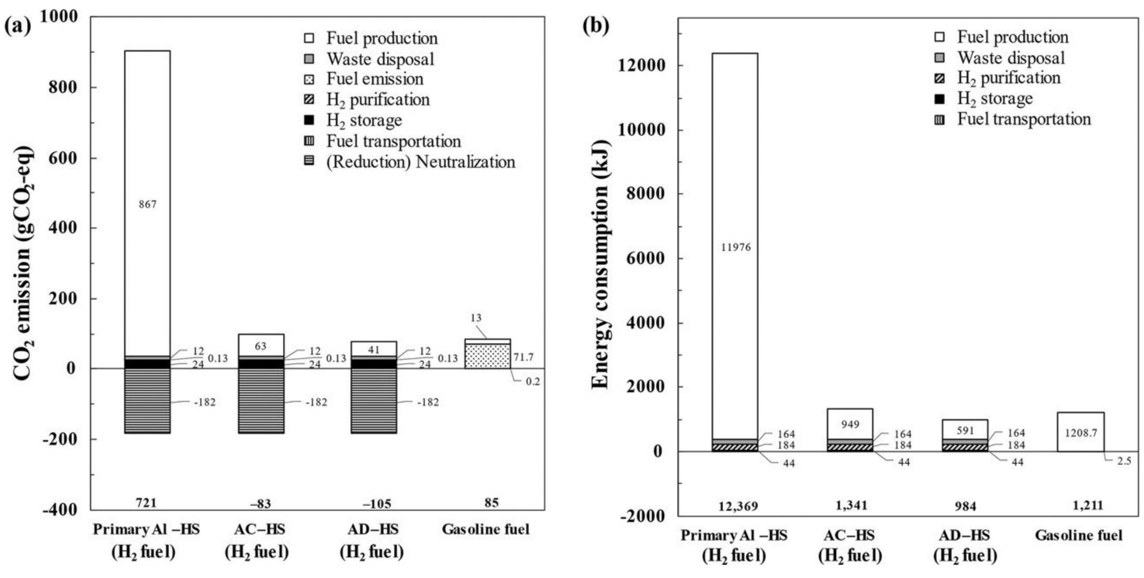

Figure 3. (a) Carbon dioxide emissions and (b) energy consumption per MJ of gasoline and hydrogen fuels. Negative carbon dioxide emissions for hydrogen fuel indicate emission reductions through neutralization. Regular text denotes values for individual processes; bold text indicates totals. (Abbreviations: Primary Al = primary aluminum, AC = aluminum cutting chips, AD = aluminum dross, HS = acidic hot spring).

５．主な発表論文等

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掲載論文のDOI（デジタルオブジェクト識別子） 10.1016/j.jece.2024.112301	査読の有無 有
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〔図書〕　計0件

〔産業財産権〕

〔その他〕

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６．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

７．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関