Available online at https://www.gyanvihar.org/researchjournals/ctm_journals.php
SGVU International Journal of Convergence of Technology and Management
E-ISSN: 2455-7528
Vol.12 Issue 2 Page No 01-07

Magnesium Alanate for Solid-State Hydrogen Storage: A Critical Review of Progress and Future Directions

Kunwar Singh Gurjar [1], Ankur Jain[1]*
[1]Centre for Renewable Energy & Storage, Suresh Gyan Vihar University, Jaipur, 302017, India

Abstract- Magnesium alanate, $Mg(AlH_4)_2$, is a complex metal hydride with a hydrogen capacity of ~9.3 wt.%, and a relatively low decomposition temperature when compared with typical magnesium hydrides, and is identified as being a promising candidate for solid-state hydrogen storage. The present article reviews the recent progress in the synthesis, structural characterization, thermal decomposition rate, and catalytic promotion of magnesium alanate. Solvent-based metathesis, mechanochemical activation synthesis, and direct ball milling methods are considered as the advantages and disadvantages of synthesis methods. The decomposition mechanism of $Mg(AlH_4)_2$ is briefly summarized, and the results show that the decomposition process can be divided into two steps: hydrogen desorption and formation of MgH_2 as an intermediate product. Catalytic modification, through the incorporation of Ti-based additives, bimetallic oxides, and destabilized composite systems, is emphasized, as it can result in a significant decrease in decomposition temperature and activation energy and increase the hydrogen desorption rate. The synergistic destabilizing effect and hydrogen release performance of composite systems such as MgH_2 – $Mg(AlH_4)_2$, $NaAlH_4$ – $Mg(AlH_4)_2$, and $LiBH_4$ – $Mg(AlH_4)_2$ are also discussed. As a whole, the literature shows that the addition of the catalyst, nanostructuring, and formation of composites are promising methods to enhance the hydrogen storage properties of magnesium alanate for practical applications in hydrogen energy.

Keywords:- Hydrogen storage, solid state hydrogen storage, Complex metal hydride, catalyst, composite.

1. INTRODUCTION

The rapid growth of energy demand around the world, combined with the critical need to reduce climate change, has pushed the shift towards a sustainable hydrogen economy forward [1–3]. Hydrogen serves as a premier carbon-free energy carrier due to its high gravimetric energy density; however, its practical application is fundamentally limited by the "storage bottleneck"[4–6]. Standard storage methods, such as compression at high pressures and cryogenic liquefaction, face serious safety issues, high energy penalties, low volumetric efficiencies, etc [7]. Therefore, the development of advanced hydrogen storage materials has become essential for practical hydrogen applications. In particular, solid-state hydrogen storage is a gamechanger, as it can safely and compactly store hydrogen atoms in solid materials through chemical or physical processes [8]. Magnesium-based hydrides are highly considered among the technologies available for this purpose due to their low cost, environmental availability, and high theoretical hydrogen capacity [9,10].

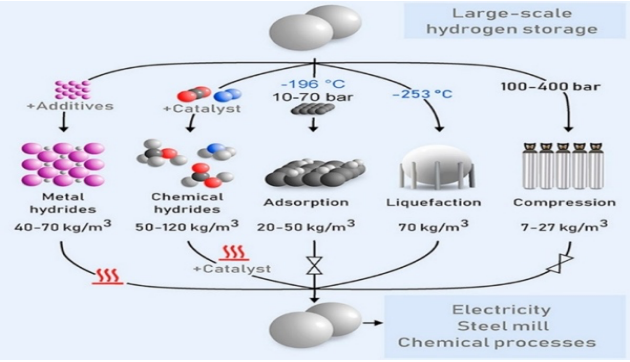

Figure 1 Comparison of Hydrogen Storage Technologies Including Metal Hydrides, Chemical Hydrides, Adsorption, Liquefaction, and Compression Methods for Large-Scale

Correspondence to: Kunwar Singh Gurjar, Centre for Renewable Energy & Storage, Suresh Gyan Vihar University, Jaipur
Corresponding author. E-mail addresses: kunwar772@gmail.com

Hydrogen Storage Applications. [11] Reprinted from Ref. (Andersson et al., 2019) under Creative Commons license.

Conventional magnesium hydride (MgH_2) has two main drawbacks: (1) high thermodynamic stability requiring temperatures > 300°C to release the hydrogen and (2) slow absorption/desorption kinetics [12,13]. Prominent researchers have thus turned their attention to Mg-based complex hydride. Magnesium alanate is a complex metal hydride and has received great attention as a high-capacity solid-state hydrogen storage material with a relatively low decomposition temperature [14,15]. One major advantage of the magnesium-aluminum bond over the conventional magnesium hydrides is that the bond destabilizes the hydride structure. This enables the release of hydrogen at lower temperatures and at higher rates, which is very beneficial for integration into mobile and stationary power systems [16].

In this study, catalytic modification of magnesium alanate, $Mg(AlH_4)_2$, has been considered for overcoming its inherent kinetic limitations and high desorption temperature. We hope to reduce the energy barrier to activation and greatly speed up the hydrogen release process by incorporating a catalyst with the base material, magnesium alanate. The systematic analysis of the influence of these catalysts on the microstructural changes and phase stability of the material during decomposition is evaluated. By means of advanced characterization, the mechanism for the use of this high-capacity magnesium alanate is elucidated by explaining the role of the catalyst in improving the desorption properties of magnesium alanate. This overall work offers an important route to the further optimization of $Mg(AlH_4)_2$ for high density solid-state hydrogen storage. The catalytic modification led to an improvement of dehydrogenation kinetics and a decrease of the dehydrogenation temperature, proving the viability of magnesium alanate in real hydrogen energy systems. In addition, ongoing catalyst design, reversibility, and composite nano-catalyst studies will further improve its potential for future clean energy storage applications.

1.1. Structure of Magnesium Alanate

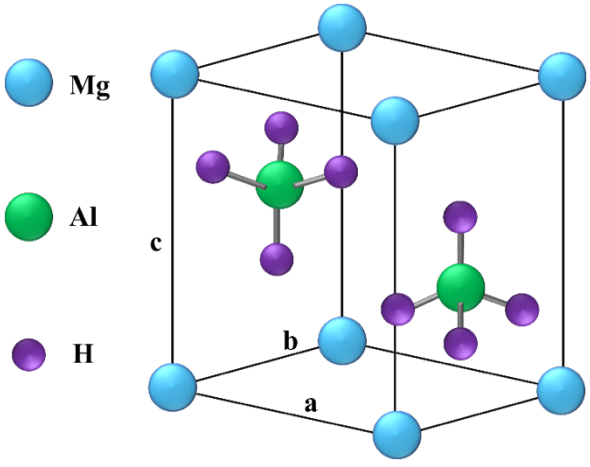

Figure 2: Crystal structure of Magnesium Alanate. [17] Reprinted from Ref. (Fossdal et al., 2019) under Creative Commons license.

The complex metal hydride magnesium alanate, $Mg(AlH_4)_2$, has a trigonal CdI_2-type layered structure. Here, the magnesium (Mg^{2+}) positions are the ones normally filled by cadmium atoms, and the aluminium hydride ions [$(AlH_4)^-$] are replaced by the iodine atoms [18]. The material crystallises in the $P\bar{3}m1$ space group with a characteristic stacking sequence along the c-axis [15]. The basic structure is of closely packed [$(AlH_4)^-$] tetrahedra double layers, with their planes perpendicular to the c axis. The double layers alternate with a single layer of magnesium atoms so that the structure has a "sandwich" as shown in Figure 1. Diffraction studies have been carried out together, and the unit-cell parameters are a = b = 5.1949 Å and c = 5.8537 Å at the reference temperature of 295 K. The lattice geometry is consistent with the lattice geometry of other hexagonal compounds having this space group: $\alpha = \beta = 90°$, $\gamma = 120°$ [18,19].

2. SYNTHESIS TECHNIQUES OF MAGNESIUM ALANATE

There are several methods which have been used to synthesize magnesium alante. Based on the specific techniques employed, we will discuss some of them in detail. The primary methods are as follows:

2.1. Solvent-Based Metathesis Synthesis

E. Wiberg and R. Bauer [20] reported the inaugural liquid-phase synthesis of magnesium alanate in 1950. They perform all operations under a strictly anhydrous argon atmosphere using standard Schlenk and glovebox techniques. They dissolve anhydrous magnesium bromide and lithium aluminum hydride in a specific ratio in freshly distilled and sodium-dried diethyl ether. The solution was added dropwise, systemically, to the stirred matrix at ambient temperature, resulting in an instant precipitation of lithium bromide (LiBr) for a salt metathesis reaction. This white suspension was agitated for several hours to ensure chemical conversion. Then the residue was dried under vacuum at room temperature. This separation method was well-known for being very inefficient and dissolving some LiBr along with the alanate. 30% of LiBr residue is present in the sample after drying.

$$2\mathrm{LiAlH_4} + MgBr_2 - dietherate \rightarrow Mg(AlH_4)_2 \cdot Et_2O + 2LiBr/\,in\,Et_2O \quad \ldots\ldots\ldots\ldots\ldots(1)$$

After a long time, Fichtner and Fuhr further modified this method by introducing a wet-chemical synthesis route followed by Soxhlet extraction, which produced $Mg(AlH_4)_2$ with a purity of about 95% [21]

Correspondence to: Kunwar Singh Gurjar, Centre for Renewable Energy & Storage, Suresh Gyan Vihar University, Jaipur
Corresponding author. E-mail addresses: kunwar772@gmail.com

A metathesis process between sodium alanate, $NaAlH_4$, and magnesium chloride ($MgCl_2$) or magnesium iodide is typically used to synthesize magnesium alanate, $Mg(AlH_4)_2$, in tetrahydrofuran (THF). Usually, the THF reaction results in $Mg(AlH_4)_2.xTHF$, a solvent adduct that needs to be vacuum-dried to extract the THF. Claudy et al. [22] suggested this approach, which is explained in equation (2).

$$2NaAlH_4 + MgCl_2 \rightarrow Mg(AlH_4)_2.4THF + 2NaCl/\ in\ THF \quad \text{..... (2)}$$

Solution-based synthesis of magnesium alanate [$Mg(AlH_4)_2$] is not a feasible method due to the formation of highly stable, non-volatile solvent adducts, requiring a shift to mechanochemical ball milling for solvent-free synthesis [23]. Thermal desolvation attempts caused material decomposition because breaking the Mg-solvent bonds requires energy exceeding the alanate's stability.

2.2. Mechanochemical Activation Synthesis

The shift to solid-state processing began when Dymova and co-workers [24] pioneered a solvent-free hydride-halide pathway. This method was later formalized into a strict way using high-energy mechanochemical ball milling. Kim et al. [23] synthesized magnesium alanate by using a stoichiometric 2:1 mixture of sodium alanate ($NaAlH_4$) and magnesium chloride ($MgCl_2$) using a SPEX 8000 mill. To prevent contamination and oxidation, all precursor handling, vial loading, and post-synthesis processing were strictly executed under an ultra-high-purity argon atmosphere inside a hermetically sealed glove box. The environmental moisture and oxygen thresholds within the workstation were rigorously maintained below 1 ppm. The metathesis reaction was performed by the high-energy mechanochemical ball milling method for a total time of 1 hour. A high ball-to-powder weight ratio (BPR) of about 35:1 was used to contribute high mass-specific kinetic energy and intimate topochemical ion exchange.

$$2NaAlH_4 + MgCl_2 \rightarrow Mg(AlH_4)_2 + 2NaCl \quad \text{.....(3)}$$

This room-temperature metathesis route yields high-purity, nanocrystalline $Mg(AlH_4)_2$ powder entirely free from solvent contamination, enabling precise structural analysis. While the product retains significant "inert" salt (NaCl) as a byproduct, the absence of solvent adducts fundamentally alters the thermal decomposition behavior of the magnesium alanate.

2.3. Direct Synthesis

The direct synthesis of magnesium alanate [$Mg(AlH_4)_2$] is achieved by dry ball milling a stoichiometric 1:2 molar ratio of magnesium hydride (MgH_2) and aluminum hydride (AlH_3) under an inert argon or hydrogen atmosphere according to the following solid-state reaction:

$$MgH_2 + 2AlH_3 \rightarrow Mg(AlH_4)_2 \quad \text{.....(4)}$$

This atom-economical pathway eliminates the heavy, inactive salt byproducts (e.g., NaCl) inherent to metathesis routes. However, its primary shortcomings stem from the severe thermal instability of the AlH_3 precursor and sluggish solid-state diffusion kinetics.

Among the synthesis methods discussed for magnesium alanate, Mechano-Chemical Activation Synthesis (MCAS) is considered more effective than conventional wet-chemical routes because it avoids the formation of solvent adducts [21]. In addition, unlike direct synthesis methods where unstable AlH_3 can decompose due to heat generated during ball milling, MCAS employs stable precursors such as $NaAlH_4$ and $MgCl_2$ under ambient conditions, making the synthesis process more controllable and reproducible [23,25]

2.4. Decomposition mechanism of Magnesium Alanate

Kim et al. [23] reported that pure magnesium alanate decomposes through a two-step thermal decomposition process, releasing a total of approximately 9.3 wt.% hydrogen. During decomposition, intermediate phases are formed, and the reaction proceeds through the following solid-state pathways:

<u>Step 1: Decomposition to Magnesium Alanate</u>

The first decomposition stage is an exothermic process that typically occurs at a relatively low temperature range between 115°C and 150°C. The alanate matrix collapses to yield magnesium hydride and metallic aluminum, releasing 6.2wt% of hydrogen:

$$Mg(AlH_4)_2 \rightarrow MgH_2 + 2Al + 3H_2 \quad \text{.....(5)}$$

Correspondence to: Kunwar Singh Gurjar, Centre for Renewable Energy & Storage, Suresh Gyan Vihar University, Jaipur
Corresponding author. E-mail addresses: kunwar772@gmail.com

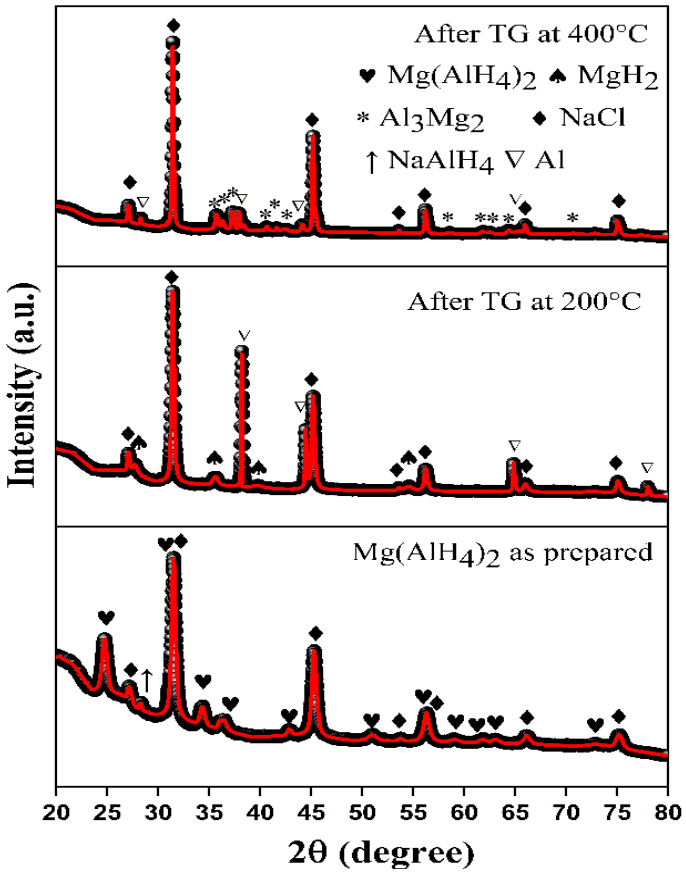

Figure 3: Decomposition mechanism of $Mg(AlH_4)_2$ explained by XRD at different temperatures.[26] Reprinted from Ref. (Fossdal et al., 2019) under Creative Commons license.

Step 2: Decomposition of Magnesium Hydride

The second stage is an endothermic reaction occurring at elevated temperatures between 240°C and 290°C. The intermediate phase formed in the first step decomposes into elemental magnesium, liberating an additional 3.1wt% of hydrogen [23]:

$$MgH_2 \rightarrow \frac{1}{2} Al_3Mg_2 + \frac{1}{2} Al + H_2 \quad \text{..... (6)}$$

Intermetallic Al-Mg Alloy Formation

The final stage takes place after the decomposition of magnesium hydride. The newly liberated, highly reactive elemental magnesium pairs with the metallic aluminum matrix to form a stable intermetallic alloy phase (Al_3Mg_2). The decomposition behavior of magnesium alanate was successfully confirmed by XRD in the present study and in our recent work, presented in Figure 2[26].

2.5. Kinetic Enhancement of Magnesium Alanate

Kim et al. [23] reported that prepared magnesium alanate by the mechanochemical activation synthesis method is solvent-free. FTIR confirmed the existence of the Al-H bond at 642cm^{-1} (bending mode) and 1837cm^{-1} (stretching mode). First decomposition of magnesium alanate starts at 115°C, and 2nd starts at 240°C. DSC shows two peaks: first exothermic (decomposition of magnesium alanate) and 2nd endothermic (decomposition of MgH_2). They calculated the enthalpy of first decomposition at 0K, which was found to be -20.4kJ/mol.

Fichtner et al. [27] synthesized $Mg(AlH_4)_2$ with 81.5% yield using a metathesis reaction in diethyl ether. After Soxhlet extraction and desolvation, 95% pure magnesium alanate was obtained with a decomposition temperature of 175 °C. XRD showed nanosized crystallites (~30 nm), indicating structural collapse after solvent removal. FTIR analysis suggested that desolvation caused cross-linking of ether adduct ribbons, forming a layered sheet-like structure.

Fossdal et al. [28] investigated the thermal decomposition behavior of $Mg(AlH_4)_2$ using in situ synchrotron X-ray diffraction. The study showed that $Mg(AlH_4)_2$ decomposes in two steps, initially forming MgH_2 and Al with hydrogen release around 110–150 °C. Further heating above 300°C caused decomposition of MgH_2 into Mg with additional hydrogen evolution. The synchrotron XRD analysis confirmed phase transformations and intermediate MgH_2 formation during decomposition.

Fichtner, Fuhr**,** et al. [16] investigated $Mg(AlH_4)_2$ as a potential hydrogen storage material. Pure unmilled $Mg(AlH_4)_2$ exhibited a peak thermal decomposition temperature of 163°C under vacuum conditions. The peak temperature for decomposition was significantly reduced by almost 45°C after the addition of 2 mol% $TiCl_3$ catalyst and subsequent ball milling. The hydrogen desorption reaction kinetics of the catalyzed and milled sample were improved from those of the untreated sample. The study showed that $TiCl_3$ and mechanochemical treatments are efficient for enhancing the thermal decomposition characteristics of magnesium alanate to be used for hydrogen storage applications.

High-energy ball milling was used in the mechanochemical synthesis of $Mg(AlH_4)_2$ by Iosub et al. [29] using MgH_2 and AlH_3 as precursors. The thermal decomposition and hydrogen storage properties of the synthesized magnesium alanate were investigated. The DSC analysis results showed that hydrogen desorption began at about 100°C, suggesting that the ball-milled sample exhibited better thermal activity. Multistep reactions, involving hydrogen release, were responsible for the decomposition process. Moreover, the activation energy of the synthesized $Mg(AlH_4)_2$ was calculated by the Kissinger equation and was found to be 119 kJ/mol.

Pang et al. [30] studied the hydrogen desorption mechanism of TiF_4 and TiF_3-catalyzed $Mg(AlH_4)_2$. The TiF_4-doped sample showed the best catalytic activity with the onset of hydrogen desorption at ~ 40 °C, which is very beneficial for practical onboard hydrogen storage

Correspondence to: Kunwar Singh Gurjar, Centre for Renewable Energy & Storage, Suresh Gyan Vihar University, Jaipur
Corresponding author. E-mail addresses: kunwar772@gmail.com

applications. In addition, the activation energy of $Mg(AlH_4)_2$ significantly decreased from 118.8 kJ/mol for the pure sample to 82.3 kJ/mol after TiF_4 addition. The study revealed that TiF_4 is an efficient catalyst for accelerating the hydrogen desorption rate and decreasing the activation energy of the decomposition of magnesium alanate.

Jain et al. [31] investigated the catalytic effect of TiF_4 with MgH_2 and other complex hydrides, $Mg(AlH_4)_2$, and $Mg(BH_4)_2$. The addition of TiF_4 dramatically affected the dehydrogenation behavior of $Mg(AlH_4)_2$, with the activation energy being lowered from the uncatalyzed value to 84 kJ/mol. The highest decomposition temperature also dropped significantly from 158°C to 100°C. The higher hydrogen desorption rate was explained by the presence of Ti–Al clusters in the ball-milled powder, which facilitated the hydrogen diffusion and promoted the decomposition reaction. The study indicated that TiF_4 is an excellent catalyst to enhance the performance of the thermal decomposition process of magnesium alanate.

Komiya et al. [32] investigated the effect of different $TiCl_3$ concentrations on the thermal decomposition behavior of $Mg(AlH_4)_2$. The catalyzed samples containing 1 mol%, 1.5 mol%, and 2.5 mol% $TiCl_3$ exhibited decomposition temperatures of 437 K, 431 K, and 417 K, respectively, at a heating rate of 5K/min. The results showed that increasing $TiCl_3$ concentration effectively lowered the decomposition temperature and enhanced hydrogen desorption behavior. The study further indicated that $Mg(AlH_4)_2$ is thermally less stable compared to other alanate hydrides, making it more favorable for low-temperature hydrogen release applications. Wang et al. [33] synthesized a MgH_2–$Mg(AlH_4)_2$composite and investigated its hydrogen desorption behavior. The composite exhibited significantly improved desorption performance compared to pure $Mg(AlH_4)_2$, initiating hydrogen release at a relatively low temperature of 90°C. Kinetic analysis showed that the activation energy of the composite decreased to 77 kJ/mol, whereas pure $Mg(AlH_4)_2$ exhibited an activation energy of 86 kJ/mol. The enhanced hydrogen desorption behavior was attributed to the destabilization effect and synergistic interaction between MgH_2 and $Mg(AlH_4)_2$.

Gurjar et al. [26] investigated $Mg(AlH_4)_2$ doped with 10 wt.% $NaNbO_3$ and $KNbO_3$ catalysts for improved dehydrogenation behavior. The $NaNbO_3$- and $KNbO_3$-doped samples released approximately 7.97 wt.% and 7.40 wt.% hydrogen, respectively, at 5°C/min. The calculated activation energies (E_a) were 92.8 kJ/mol for $NaNbO_3$ and 123 kJ/mol for $KNbO_3$, confirming the superior catalytic performance of $NaNbO_3$.

Hudson et al. [34] investigated the hydrogen desorption behavior of a composite system of $Mg(AlH_4)_2$ and $NaAlH_4$ $(0 < a < 1,\ b \geq 1)$. The composite exhibited enhanced desorption performance compared to pure sodium alanate. Thermal analysis revealed that the hydrogen desorption temperature of $NaAlH_4$ decreased significantly from 190°C to 140°C after the addition of $Mg(AlH_4)_2$. The improved desorption behavior was attributed to the destabilization effect and interaction between the two alanate hydrides, which promoted faster hydrogen release kinetics.

Liu et al. [35] synthesized a $6LiBH_4$– $Mg(AlH_4)_2$ composite system and investigated its thermal properties. The composite exhibited improved hydrogen desorption behavior with a reduction in the onset decomposition temperature by approximately 40 °C compared to the pure material. For the same system, the activation energy is 109.7kJ/mol, calculated by Pang et al [36].

Liu et al. [37]synthesized sub-micron $Mg(AlH_4)_2$ with a purity of approximately 96% and investigated its hydrogen storage properties. The material exhibited a hydrogen release capacity of nearly 9 wt.% with an onset decomposition temperature of about 125°C. Kinetic analysis showed an activation energy of 123 kJ/mol for the dehydrogenation process. Furthermore, the sample demonstrated partial reversibility by reabsorbing approximately 2.3 wt.% hydrogen under a hydrogen pressure of 100 bar.

3. CONCLUSION

The reviewed studies clearly demonstrate that the hydrogen desorption behavior of $Mg(AlH_4)_2$ can be significantly improved through mechanochemical synthesis, nanostructuring, composite formation, and catalyst addition. Among the different catalysts studied, Ti-based additives such as $TiCl_3$ and TiF_4 were found to be the most effective in improving the dehydrogenation behavior of magnesium alanate by lowering the decomposition temperature and reducing the activation energy. Furthermore, oxide catalysts and destabilized composite systems also contributed to faster hydrogen release kinetics and improved thermal performance. Overall, the literature confirms that catalytic modification plays a crucial role in improving the dehydrogenation performance and practical hydrogen storage potential of magnesium alanate. The issues that need further study are to develop low-cost catalysts, to enhance the dehydrogenation performance under moderate conditions, and to determine the design of nanostructured composite systems that can be used to obtain practical and commercial hydrogen storage performance.

REFERENCE

[1] M. Conte, A. Iacobazzi, M. Ronchetti, and R. Vellone, "Hydrogen economy for a sustainable development: state-of-the-art and technological perspectives."

[2] A. M. Sadeq *et al.*, "Hydrogen energy systems: Technologies, trends, and future prospects," Aug. 20, 2024, *Elsevier B.V.* doi: 10.1016/j.scitotenv.2024.173622.

[3] I. P. Jain, "Hydrogen the fuel for 21st century," *Int. J. Hydrogen Energy*, vol. 34, no. 17, pp. 7368–7378, 2009, doi: 10.1016/j.ijhydene.2009.05.093.

[4] M. Yue, H. Lambert, E. Pahon, R. Roche, S. Jemei, and D. Hissel, "Hydrogen energy systems: A critical review of technologies, applications, trends and

Correspondence to: Kunwar Singh Gurjar, Centre for Renewable Energy & Storage, Suresh Gyan Vihar University, Jaipur
Corresponding author. E-mail addresses: kunwar772@gmail.com

challenges," Aug. 01, 2021, *Elsevier Ltd*. doi: 10.1016/j.rser.2021.111180.

[5] M. M. Hossain Bhuiyan and Z. Siddique, "Hydrogen as an alternative fuel: A comprehensive review of challenges and opportunities in production, storage, and transportation," Feb. 10, 2025, *Elsevier Ltd*. doi: 10.1016/j.ijhydene.2025.01.033.

[6] J. O. Abe, A. P. I. Popoola, E. Ajenifuja, and O. M. Popoola, "Hydrogen energy, economy and storage: Review and recommendation," Jun. 07, 2019, *Elsevier Ltd*. doi: 10.1016/j.ijhydene.2019.04.068.

[7] W. Suwaileh *et al.*, "Exploring hydrogen fuel as a sustainable solution for zero-emission aviation: Production, storage, and engine adaptation challenges," Apr. 23, 2025, *Elsevier Ltd*. doi: 10.1016/j.ijhydene.2025.03.348.

[8] P. Prachi R., W. Mahesh M., and G. Aneesh C., "A Review on Solid State Hydrogen Storage Material," *Advances in Energy and Power*, vol. 4, no. 2, pp. 11–22, Jun. 2016, doi: 10.13189/aep.2016.040202.

[9] B. Rathi, S. Agarwal, K. Shrivastava, M. Kumar, and A. Jain, "Recent advances in designing metal oxide-based catalysts to enhance the sorption kinetics of magnesium hydride," Jan. 31, 2024, *Elsevier Ltd*. doi: 10.1016/j.ijhydene.2023.12.031.

[10] I. P. Jain, C. Lal, and A. Jain, "Hydrogen storage in Mg: A most promising material," *Int. J. Hydrogen Energy*, vol. 35, no. 10, pp. 5133–5144, May 2010, doi: 10.1016/j.ijhydene.2009.08.088.

[11] J. Andersson and S. Grönkvist, "Large-scale storage of hydrogen," *Int. J. Hydrogen Energy*, vol. 44, no. 23, pp. 11901–11919, May 2019, doi: 10.1016/j.ijhydene.2019.03.063.

[12] S. K. Saini, A. Sharma, K. Shrivastava, R. Sahu, T. Ichikawa, and A. Jain, "Boosting hydrogenation properties of MgH2: Li4Ti5O12's impact on the kinetics," *Int. J. Hydrogen Energy*, vol. 200, Jan. 2026, doi: 10.1016/j.ijhydene.2025.152902.

[13] S. K. Saini *et al.*, "Catalytic alteration in hydrogen storage properties of MgH2 by adding CaTiO3," *J. Energy Storage*, vol. 132, Oct. 2025, doi: 10.1016/j.est.2025.117958.

[14] I. P. Jain, P. Jain, and A. Jain, "Novel hydrogen storage materials: A review of lightweight complex hydridespuye," Jul. 23, 2010, *Elsevier Ltd*. doi: 10.1016/j.jallcom.2010.04.250.

[15] K. Suárez-Alcántara, J. R. Tena-Garcia, and R. Guerrero-Ortiz, "Alanates, a comprehensive review," 2019, *MDPI AG*. doi: 10.3390/ma12172724.

[16] M. Fichtner, O. Fuhr, and O. Kircher, "Magnesium alanate - A material for reversible hydrogen storage?," in *Journal of Alloys and Compounds*, Aug. 2003, pp. 418–422. doi: 10.1016/S0925-8388(02)01236-7.

[17] A. Fossdal, H. W. Brinks, M. Fichtner, and B. C. Hauback, "Determination of the crystal structure of Mg(AlH4)2 by combined X-ray and neutron diffraction," *J. Alloys Compd.*, vol. 387, no. 1–2, pp. 47–51, Jan. 2005, doi: 10.1016/j.jallcom.2004.06.050.

[18] Z. Qian *et al.*, "Ab initio screening of doped Mg(AlH4)2 systems for conversion-type lithium storage," *Materials*, vol. 12, no. 16, Aug. 2019, doi: 10.3390/ma12162599.

[19] E. Wiberg and R. Bauer, "Notizen: Zur Kenntnis eines Magnesium-bor-wasserstoffs $Mg(AlH_4)_2$," *Zeitschrift für Naturforschung B*, vol. 5, no. 7, pp. 397–398, Jul. 1950, doi: 10.1515/znb-1950-0712.

[20] M. Fichtner and O. Fuhr, "alanate and two solvent adducts," 2002. [Online]. Available: www.elsevier.com/locate/jallcomSynthesisandstructuresofmagnesium

[21] P. Claudy, B. Bonnetot, and J. M. Letoffe, "Preparation et proprietes physico-chimiques de l'alanate de magnesium Mg(AlH4)2," *Journal of Thermal Analysis*, vol. 15, no. 1, pp. 119–128, Feb. 1979, doi: 10.1007/BF01910203.

[22] Y. Kim, E. K. Lee, J. H. Shim, Y. W. Cho, and K. B. Yoon, "Mechanochemical synthesis and thermal decomposition of Mg(AlH4)2," *J. Alloys Compd.*, vol. 422, no. 1–2, pp. 283–287, Sep. 2006, doi: 10.1016/j.jallcom.2005.11.063.

[23] T. N. Dymova, N. N. Mal'tseva, V. N. Konoplev, A. I. Golovanova, D. P. Aleksandrov, and A. S. Sizareva, "Solid-Phase Solvate-Free Formation of Magnesium Hydroaluminates Mg(AlH4)2and MgAlH5upon Mechanochemical Activation or Heating of Magnesium Hydride and Aluminum Chloride Mixtures," *Russian Journal of Coordination Chemistry*, vol. 29, no. 6, pp. 385–389, Jun. 2003, doi: 10.1023/A:1024025925617.

[24] R. A. Varin, C. Chiu, T. Czujko, and Z. Wronski, "Mechano-chemical activation synthesis (MCAS) of nanocrystalline magnesium alanate hydride [Mg(AlH4)2] and its hydrogen desorption properties," *J. Alloys Compd.*, vol. 439, no. 1–2, pp. 302–311, Jul. 2007, doi: 10.1016/j.jallcom.2006.08.080.

[25] K. S. Gurjar *et al.*, "Probing the reaction mechanism of dehydrogenation of catalyzed Mg(AlH4)2 by alkali-transition metal based bimetallic oxides," *Mater. Today Chem.*, vol. 49, Oct. 2025, doi: 10.1016/j.mtchem.2025.103052.

[26] M. Fichtner and O. Fuhr, "alanate and two solvent adducts," 2002. [Online]. Available: www.elsevier.com/locate/jallcomSynthesisandstructuresofmagnesium

[27] A. Fossdal, H. W. Brinks, M. Fichtner, and B. C. Hauback, "Thermal decomposition of Mg(AlH4)2 studied by in situ synchrotron X-ray diffraction," *J. Alloys Compd.*, vol. 404–406, no. SPEC. ISS., pp. 752–756, Dec. 2005, doi: 10.1016/j.jallcom.2004.12.169.

[28] V. Iosub, T. Matsunaga, K. Tange, and M. Ishikiriyama, "Direct synthesis of Mg(AlH4)2 and CaAlH5 crystalline compounds by ball milling and

Correspondence to: Kunwar Singh Gurjar, Centre for Renewable Energy & Storage, Suresh Gyan Vihar University, Jaipur
Corresponding author. E-mail addresses: kunwar772@gmail.com

their potential as hydrogen storage materials," *Int. J. Hydrogen Energy*, vol. 34, no. 2, pp. 906–912, Jan. 2009, doi: 10.1016/j.ijhydene.2008.11.013.

[29] Y. Pang, Y. Liu, X. Zhang, M. Gao, and H. Pan, "TiF4-doped Mg(AlH4)2 with significantly improved dehydrogenation properties," *Int. J. Hydrogen Energy*, vol. 38, no. 30, pp. 13343–13351, Oct. 2013, doi: 10.1016/j.ijhydene.2013.07.099.

[30] A. Jain *et al.*, "How does TiF_4 affect the decomposition of MgH_2 and its complex variants? – An XPS investigation," *J. Mater. Chem. A Mater.*, vol. 5, no. 30, pp. 15543–15551, 2017, doi: 10.1039/C7TA03081A.

[31] K. Komiya *et al.*, "Synthesis and dehydrogenation of M(AlH4)2 (M = Mg, Ca)," *J. Alloys Compd.*, vol. 446–447, pp. 237–241, Oct. 2007, doi: 10.1016/j.jallcom.2007.01.119.

[32] Y. Wang, Y. Wang, X. Wang, H. Zhang, L. Jiao, and H. Yuan, "Destabilization effects of Mg(AlH4)2 on MgH2: Improved desorption performances and its reaction mechanism," in *International Journal of Hydrogen Energy*, Elsevier Ltd, Oct. 2014, pp. 17747–17753. doi: 10.1016/j.ijhydene.2014.08.117.

[33] M. Sterlin Leo Hudson, D. Pukazhselvan, G. Irene Sheeja, and O. N. Srivastava, "Studies on synthesis and dehydrogenation behavior of magnesium alanate and magnesium-sodium alanate mixture," *Int. J. Hydrogen Energy*, vol. 32, no. 18, pp. 4933–4938, Dec. 2007, doi: 10.1016/j.ijhydene.2007.07.068.

[34] D. Liu *et al.*, "Superior hydrogen storage properties of LiBH4 catalyzed by Mg(AlH4)2," *Chemical Communications*, vol. 47, no. 20, p. 5741, 2011, doi: 10.1039/c1cc11238d.

[35] Y. Pang, Y. Liu, X. Zhang, Y. Li, M. Gao, and H. Pan, "New insights into the effects of NaCl and LiCl on the hydrogen storage behaviours of a $6LiBH_4$–$Mg(AlH_4)_2$ composite," *RSC Adv.*, vol. 5, no. 16, pp. 12144–12151, 2015, doi: 10.1039/C4RA15187A.

[36] Y. Liu, Y. Pang, X. Zhang, Y. Zhou, M. Gao, and H. Pan, "Synthesis and hydrogen storage thermodynamics and kinetics of Mg(AlH 4) 2 submicron rods," *Int. J. Hydrogen Energy*, vol. 37, no. 23, pp. 18148–18154, Dec. 2012, doi: 10.1016/j.ijhydene.2012.09.081.

Correspondence to: Kunwar Singh Gurjar, Centre for Renewable Energy & Storage, Suresh Gyan Vihar University, Jaipur
Corresponding author. E-mail addresses: kunwar772@gmail.com