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**Stationary Storage
and Purification of
Hydrogen Using
Nickel-Coated
Magnesium Powder**

Final Technical Report

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Table of Contents

1.0	Background	1
2.0	Advantages and Limitations of Magnesium as a Hydridable Metal	2
3.0	Description of Concept Investigated	4
4.0	Applications for This Concept	6
4.1	Hydrogen Fueling Stations	6
4.2	Fuel Cell Vehicles	7
5.0	Results	8
5.1	Experimental Results	8
5.1.1	Sample Preparation and Testing	8
5.1.2	Sample Testing	11
5.2	Results of Deliberations	17
5.2.1	On Dealing with the Limited Life of Mg_3N_2 Coatings	17
5.2.2	Alternative Coatings	17
5.2.3	Coatings for Pellets	18
5.3	Results of Reading Current Literature	18
6.0	Conclusions	20
7.0	Recommendations	21

List of Figures

1. Schematic Flow Diagram of Device to Accept Steady Flow of Reformate and Deliver Intermittent Flow of Hydrogen	6
2. Typical Temperature and Pressure During Degassing	10
3. Movement Between Two Pressure Composition Isotherms	11
4. Un-coated Magnesium Particles Dehydriding in Pure Hydrogen	12
5. Coated Magnesium Particles Dehydriding and Hydriding in Pure Hydrogen	13
6. Coated Magnesium Particles Dehydriding and Hydriding in Quasi-Reformate	14
7. Recovery of NCMP After Exposure to CO ₂	16
8. Recovery of NCMP After Exposure to CO	16

Stationary Storage and Purification of Hydrogen Using Nickel Coated Magnesium Particles

FINAL TECHNICAL REPORT

Contract No. DE-FC36-96G010142

1.0 Background

This project originated with DOE contract number ZAR-4-13294-03 resulting from ADL's proposal in response to an NREL competitive procurement. That procurement sought the development of means to maximize the efficiency with which hydrogen could be stored and retrieved; specifically, NREL's targets were 75% (round trip energy efficiency) and a cost less than 50% of the value of the delivered hydrogen

We proposed a scheme to store hydrogen using a metal hydride that is thermally coupled to a phase change material. The heat generated during storage (that is, the heat of the hydriding reaction) was stored as heat of fusion by melting the phase change material. The heat required to release the hydrogen (that is, the heat of the dehydriding reaction) was supplied by recovering that same heat of fusion by encouraging that phase change material to solidify.

We designed, built and tested an apparatus according to that proposed scheme. That design and those tests, both reported in the Final Report¹ for that contract were successful. Specifically, they demonstrated that a round trip energy efficiency of 90%, as compared with the NREL goal of 75%, could be achieved with a sufficiently large apparatus operated on a daily cycle. They also demonstrated that this larger apparatus would cost approximately 33%, as compared with the NREL goal of 50%, of the cost of the delivered hydrogen to amortize and operate.

It was our selection of nickel coated magnesium particles (NCMP) as the hydriding material (for reasons outlined in the following section) that led us to consider the following question: Could alternative (or additional) coatings overcome the tendency of magnesium to be poisoned by water, carbon dioxide or carbon monoxide? Should such a coating be possible, it would greatly expand the applications for this technology.

We therefore proposed to DOE in 1996 that we investigate the fabrication and effectiveness of coatings designed to render magnesium particles capable of hydriding even in the presence of water, carbon dioxide or carbon monoxide. This proposal resulted in the original issuance of the present contract (DE-FC36-96G010142). Our initial success in this endeavor, reported at the 1997 U.S. DOE Hydrogen Program Review led us to propose later in 1997 that this contract be extended. It has since been extended, at no additional cost to DOE, to 12/31/99.

¹ "High Efficiency Stationary Hydrogen Storage," final technical report to NREL, Arthur D. Little Reference No. 45781, February, 1995.

2.0 Advantages and Limitations of Magnesium as a Hydridable Metal

Pure magnesium has two well known major advantages as a hydridable metal:

1. Retrievable hydrogen constitutes a greater weight percentage (7.6%) of magnesium hydride than of any other metal hydride.
2. Magnesium is relatively inexpensive, as hydridable materials go.

The rarity with which it is used to store hydrogen is explained by its disadvantages, some of which it shares with other hydridable materials and some of which can be circumvented:

1. *Its reaction kinetics are poor.* This can be remedied by catalyzing the dissociation of molecular hydrogen at or near the surface of the magnesium particles. Bogdanovic² has demonstrated the effectiveness of co-macerating the magnesium powder with powdered nickel to accomplish this. In our earlier, NREL-sponsored effort, we demonstrated the effectiveness of coating the magnesium powder with a thin layer of nickel at accomplishing the same thing.
2. *The considerable energy required to dehydride magnesium hydride must be provided at inconveniently high temperatures.* The energy required to dehydride magnesium hydride is 27% of the higher heating value (HHV) of the hydrogen released; by contrast, most metal hydrides require roughly 10% of the HHV of hydrogen to dehydride. In some applications for hydrogen released from storage, this energy can be provided by waste heat such as the sensible heat in engine exhaust or in fuel cell tailgas. For magnesium hydride, however, this dehydriding energy must be provided at 350-400°C, which is well above vehicular fuel cell (that is, PEMFC) operating temperatures.

This disadvantage can be circumvented, or at least tolerated, if the magnesium hydride can be maintained near 350-400°C throughout the storage/retrieval cycle. This can be accomplished by means of the scheme described in Section 1.0, that is by storing the hydriding energy as heat of fusion. Though we proposed this concept to NREL, and demonstrated experimentally its applicability to magnesium with NREL sponsorship, we subsequently learned that this concept had been patented by Sandrock and Snape³ for hydridable materials in general.

Hydrogen is not generally produced at 350-400°C, though. It typically leaves the fuel processor at 150°C. However, the sensible heat required to heat hydrogen from 150°C to 400°C is only 2.5% of its higher heating value.

²Borislav Bogdanovic, "Method of Preparing Active Magnesium-Hydride or Magnesium Hydrogen-Storer Systems," US Patent No. 5,199,972, April 6, 1993.

³Gary D. Sandrock and Edwin Snape, "Reaction Heat Storage Method for Hydride Tanks," US Patent No. 4,566,281, January 28, 1986.

3. *Magnesium will react with some of the non-hydrogen species found in reformat.*
This limitation does not apply to using magnesium to store pure hydrogen, but it does apply to using magnesium to selectively absorb hydrogen from reformat. In particular, it can be poisoned by three species commonly found in reformat – carbon dioxide, carbon monoxide and water vapor. This limitation also applies to using nickel-coated magnesium to selectively absorb hydrogen from reformat.

This limitation is one that magnesium shares with virtually every other hydridable material.⁴ Were this limitation to be neutralized for magnesium (or, indeed, for any hydridable material) it would be possible to use magnesium (or the other hydridable material) to simultaneously purify and store hydrogen. This fact was the impetus for this research effort.

⁴ We will discuss a reported exception in Section 6.

3.0 Description of Concept Investigated

Simply put, our concept consists of a coating (or a coating system) that can be applied to magnesium particles (or to particles of another hydridable material), which coating permits hydrogen to react with the magnesium while preventing other species from reacting with the magnesium.

Upon reflection, we recognized that a suitable coating system for magnesium particles should possess the following five characteristics:

1. *Hydrogen Permselectivity* - It must pass hydrogen, but it must not pass any other species with which the magnesium might react.
2. *Chemical Inertia* - It must not itself react with the other species, lest it lose its hydrogen-permselectivity.
3. *Kinetics* - It should catalyze the dissociation of hydrogen molecules, so that the hydriding reaction kinetics are enhanced.
4. *Cost* - The coating should be inexpensive.
5. *Durability* - The coating must remain attached to the magnesium.

We recognized that a single coating might not possess all of these characteristics. We thus refer to a 'coating system,' which might consist of multiple coatings.

Hydrogen can be separated from the other species in a hydrogen-rich gas mixture, such as reformat, by pressurizing that mixture and exposing it to a hydrogen-permselective membrane the other side of which is held at a lower pressure. Usually these membranes are supported by some sort of substrate, and the thickness of that membrane is determined by a compromise: both performance and cost favor thin membranes, while the ability to withstand high pressure drops and the ability to use substrates with practical pore sizes both favor thick membranes. Likewise, the pore size of that substrate is determined by a compromise: smaller pores permit thinner membranes, but smaller pores also generate larger pressure drops across the substrate.

Alternatively, if the membrane is deployed as a coating on an essentially spherical particle, then the membrane can be very thin indeed, for the characteristic dimension of the surface irregularities (the gap that must be spanned by the membrane) is comparable to the crystal lattice spacing. The membrane can be so thin that the natural gaps that attend very thin layers, such as lattice discontinuities, exist in the coating. If these natural gaps exist, and if they are small enough to permit the passage of hydrogen but not other species, then this coating constitutes a hydrogen-permselective membrane. And if that spherical particle is made of a hydridable material such as magnesium, then the coated particle should be able to absorb hydrogen selectively from a hydrogen-rich gas mixture.

Conceptually, at least, a magnesium particle should be able to support a membrane coating that is so thin as to be hydrogen-permselective. Thus, if we can make the coating thin enough, it should satisfy our first criterion, hydrogen-permselectivity.

We reasoned that the following two criteria could be satisfied at once if the coating were made from magnesium – that is, if magnesium is one of the reactants used to form the coating.

1. Such a coating should be durable, in the sense that it should remain attached to the particle. After all, the surface layer of magnesium that forms the coating is already bonded to the layers of magnesium beneath it in the crystal lattice.
2. Such a coating could be inherently self-protective. Once the coating forms, the non-magnesium reactant that forms the coating could be prevented from contacting, thus reacting with, the magnesium. Once the coating is sufficiently formed so that the coverage is complete except for gaps the size of lattice discontinuities, then the reaction that forms the coating can form no more.

We also reasoned that any coating, if thin enough, is an inexpensive coating.

Thus, if magnesium were to react with another species to form a thin, self-protective coating, three of our five criteria would be met – hydrogen permselectivity, durability and cost. It remained to select the coating so as to meet the other two criteria – chemical inertness and kinetics.

We then recognized that kinetics enhancement does not necessarily require a coating. The catalyst could be powdered and mixed with the coated magnesium particles, much as Bogdanovic achieved kinetics enhancement by mixing nickel powder with magnesium particles.⁵ Alternatively, the catalyst could be applied as a discontinuous coating on top of the first, or primary, coating, for due to the phenomenon known as “spillover” the hydrogen molecule, once dissociated into hydrogen atoms, can migrate over the surface of the coated magnesium particle for some distance before they are re-associated into a hydrogen molecule.

Thus, if magnesium were to react with another species to form a thin, self-protective coating and if dissociation catalysis were to be provided by something other than the primary coating, then that primary coating need only meet the further criterion of chemical inertness to carbon monoxide, carbon dioxide and water vapor.

One could refer to magnesium powder coated with a thin, chemically inert layer as reformat-tolerant magnesium.

⁵ Bogdanovic, *op. cit.*

4.0 Applications for this Concept

We have identified two applications for this concept, once realized: hydrogen fuel stations and fuel cell vehicles with on-board reformers.

4.1 Hydrogen Fueling Stations

The concept of a coated magnesium particle that can selectively absorb hydrogen from reformat, and subsequently discharge pure hydrogen, has application to reformer-based hydrogen fueling stations.

Hydrogen is typically produced by steam reforming methane, then purified by a pressure swing adsorber (PSA), and stored as a compressed gas. Storage is necessary because the projected peak refueling load is three times as large as the average fueling load. While large scale hydrogen production generally involves hydrogen storage and/or transshipment as liquid, rather than as a compressed gas, hydrogen fueling stations are projected to be of a size that could only justify liquefaction for stationary storage if hydrogen were to be stored on board the vehicle as liquid.

Magnesium particles coated with a hydrogen-permselective material would permit the construction of a device that could simultaneously purify and store the hydrogen. This device could replace both the PSA and much, if not all of the compressed gas storage.

Such a device is represented schematically by Figure 1. This device could accept a steady flow of reformat from a methane reformer, and it could satisfy an intermittent demand for hydrogen by a small industrial user of hydrogen or by a hydrogen fueling station. The mismatch between reformat supply and hydrogen demand is accommodated by the hydrogen storage capacity of the coated magnesium particles. The thermal mismatch between heat rejected by the hydriding bed and the heat accepted by the dehydriding bed is accommodated by the thermal storage capacity of the phase change material.

Figure 1 - Schematic Flow Diagram of Device to Accept Steady Flow of Reformat and Deliver Intermittent Flow of Hydrogen

4.2 Fuel Cell Vehicles

Fuel cell vehicles utilizing on-board reformers would benefit greatly from the ability to store some of the reformat that is generated during normal operation for use during the subsequent start-up. However, compressed gas storage of reformat is impractical, requiring both a multistage compressor (unless the on-board reformer operates at high pressure) and a high pressure storage cylinder. A single, small bed of reformat-tolerant magnesium powder could store enough hydrogen to run the fuel cell while the fuel processor is warming up. It could also be used to supply additional, pure, hydrogen to meet peak loads.

5.0 Results

We wish to report the results of our experiments, of our subsequent deliberations and of our perusal of related current literature.

5.1 Experimental Results

The first coating we tried was magnesium nitride, Mg_3N_2 .

We applied this Mg_3N_2 coating by fluidizing un-coated magnesium particles (that is, with no nickel coating) in a mixture of 96% hydrogen and 4% ammonia (NH_3) for ~20 minutes at 527°C . At this temperature the ammonia reacts with the surface layer of the magnesium particles according to the reaction

The fluidized bed in which we performed this chemical vapor deposition process was a vertically oriented ~10" length of 1/2" stainless steel tube with VCR fittings at the top and bottom. A VCR gasket with a 7 micron sintered-metal center filter was used in place of a normal VCR gasket to seal the power in the reactor.

We determined the fluidizing velocity for these particles by putting these in a similar fluidizing bed with the stainless steel tube replaced with a glass tube, so that we could determine the fluidizing velocity by direct observation. We then corrected for the difference between room and operating temperatures by recognizing that the mass flow rate necessary for fluidization varies with the density (ρ_{H} , which decreases with temperature) and the viscosity (μ_{H} , which increases with temperature) of hydrogen as follows:

$$\text{Mass flow rate} \sim \rho_{\text{H}} / \mu_{\text{H}}$$

and arrived at 41 cm/min as the fluidizing velocity for those particles at 527°C and atmospheric pressure.

We then established that the magnesium particles thus coated with Mg_3N_2 did in fact hydride and dehydride when exposed to reasonably pure (1.0 grade, which is 99.99% pure) hydrogen.

First, a word about our method of measuring the extent to which a metal is hydrided and dehydrided.

5.1.1 Sample Preparation and Testing

Samples of treated magnesium were tested in two types of test reactors after first degassing at elevated temperature under vacuum. The general procedure we used was as follows:

1. Place the sample in the test section, seal the test section, and then leak test first by evacuating and then by filling with pressurized H₂ and “sniffing” all connections with a hand-held hydrogen detection system.
2. Evacuate the test section and start heating it (typically to 350°C).
3. Monitor the pressure (vacuum) to observe the typical pressure increase as degassing occurred (believed to be predominately H₂O, above 100°C), and the subsequent pressure decrease (typically to less than 150 mTorr), indicating that degassing is complete. An example of the temperature and pressure readings obtained during degassing is shown in Figure 2.
4. Maintain the high vacuum and high temperature for one or more hours to ensure that degassing is complete.
5. Reduce the temperature to 350°C or below, and pressurize the test section to 400-500 psig with H₂. Maintain this pressure for 6 or more hours to completely hydride the sample (if a sample had slow enough kinetics to not hydride in 6 hours at 350°C, we were not interested in it).
6. Reduce the pressure to approx. 110% of the MgH₂ equilibrium pressure (P_{eq})⁶ at the chosen initial test temperature (usually 300°C), and allow the pressure to stabilize. Further reduce the pressure to approx. 95 % of P_{eq} and observe the kinetics of the pressure recovery. When the pressure recovered to 100 – 105% of P_{eq} , we deemed that the sample was on the plateau of the adsorption-desorption isotherm, to the right of center of the isotherm (P_{eq} is defined as the center of this plateau).
7. Increase the sample temperature and record the resulting pressure increase. The size of the expected pressure increase is illustrated in Figure 3 as movement from point A to point B. The decrease in % H₂ from point A to point B is the increased amount of hydrogen that is contained in the ullage of the test section. (The quantity of H₂ in the ullage increases because the percentage pressure increase is greater than the percentage temperature increase).
8. Start the temperature controller to provide the desired temperature oscillations (and resulting pressure oscillations)⁷. Ensure that the data logger is operating. (Data was typically logged every 10 minutes).

⁶ The equation $P = \exp(16.63 - 9314/T)$, T in degrees K, P in atmospheres, was used to calculate the equilibrium pressure for MgH₂.

⁷ Initially, hydriding was accomplished in the same vessel that was used for making the Mg₃N₂. Data was recorded manually, as we were primarily interested in the permeability of the coating and the resulting initial kinetics of the hydriding. When it became desirable to record multiple cycles of hydriding/dehydriding from mixtures of gases, a separate test apparatus was constructed that contained 6 independent test sections and automatic data logging of test section pressures and temperatures.

9. After determining the nature of the hydriding/dehydriding of the sample with pure hydrogen, stop the temperature oscillations and introduce the desired quantity of “poison” gas (CO, CO₂, and/or H₂O).
10. Restart the temperature oscillations and observe the resulting change in hydriding/dehydriding behavior.

Figure 2 – Typical Temperature and Pressure during Degassing

Figure 3 – Movement between two Pressure Composition Isotherms

5.1.2 Sample Testing

Bogdanovic⁸ has shown that the reaction kinetics of pure magnesium are poor relative to a mixture of Mg and a small amount of Ni. We previously⁹ found that nickel-coated magnesium powder (NCMP) displayed reaction kinetics with hydrogen that were equal to or better than those found with a mixture of magnesium and nickel. We also found, however, that the NCMP could be poisoned by the presence of H₂O, CO, and CO₂. We therefore investigated the kinetics of magnesium nitride coated magnesium particles (MNCMP).

Figure 4 shows the results of dehydriding of un-coated magnesium particles mixed with platinum black in pure hydrogen in our preliminary reactor test vessel. A comparison of the actual pressure rise in the vessel with the pressure rise expected in the absence of hydriding/dehydriding (lower solid line in Figure 4) shows that the particles did indeed dehydride.

⁸ Bogdanovic, *op. cit.*

⁹ "High Efficiency Stationary Hydrogen Storage," Final Technical Report to National Renewable Energy Laboratory by Arthur D. Little, Inc., February 23, 1995.

Figure 4 – Un-coated Magnesium Particles Dehydriding in Pure Hydrogen

Figure 5 shows the results of dehydriding/hydriding of MNCMP in pure hydrogen. Again, the pressure is seen to rise and fall much more than is predicted by the perfect gas law (bottom solid line), indicating that the particles dehydrided and then hydrided as the temperature was increased and then decreased.

Figure 5 - Coated Magnesium Particles Dehydriding and Hydriding in Pure Hydrogen

We then investigated the hydriding/dehydriding properties of MNCMP in the presence of “quasi-reformate” (a mixture of one part steam, one part CO₂, and two parts hydrogen). The results of our preliminary tests are shown in Figure 6. In this gas mixture, the un-coated particles were observed to “behave like sand” (that is, they exhibited no tendency to hydride/dehydride) as the non-hydrogen species reacted with the magnesium thus preventing its hydriding/dehydriding; the pressure rose and fell with temperature only in accord with the perfect gas laws. However, the coated particles in the quasi-reformate were observed to hydride and dehydride over eleven cycles.

Figure 6 - Coated Magnesium Particles Dehydriding and Hydriding in Quasi-Reformate

Unfortunately, we subsequently discovered that the magnesium nitride coating does not remain hydrogen-permselective for an extended period. An indication of this decay in hydriding performance can be seen in the last cycle in Figure 6. The H_2 partial pressure does not recover to the same level that it did in the previous cycles. At the time, however, we assumed that the reduced pressure recovery was a result of an inaccuracy in the manual data recording.

In order to better measure the effects of repeated cycling of materials, we greatly improved the coated particle testing apparatus. It no longer became necessary to coat and test the particles in the same reactor. It became possible to coat particles in the original reactor, and to test six separate samples of coated particles simultaneously in six separate test sections, shown below.

Each of these test sections has its own electric heater, controlled by its own programmable controller. The temperatures and pressures within all six test sections are monitored by thermocouples and pressure transducers, all connected to a datalogger, as illustrated below.

It is possible to retrieve the data from that datalogger remotely, using a pair of modems.

Using this new facility, we determined that, indeed, the MNCMP hydriding performance decayed after many cycles. Suspecting that the Mg_3N_2 coating may have disappeared, and thus ceased to protect the magnesium, we checked the thermodynamic equilibrium of the reaction that formed the Mg_3N_2 coating in the first place and found that, at the temperatures at which we hydride/dehydride and in the absence of NH_3 that reaction slowly reverses. Thus, magnesium particles coated with Mg_3N_2 cannot be expected to last for more than a few weeks.

We also used this improved facility to determine the sensitivity of NCMP to CO_2 , H_2O and CO , individually and simultaneously. This showed that NCMP is inert to neither CO_2 , H_2O nor CO .

Interestingly, NCMP can recover from exposure to a fixed amount of CO , as shown in Figure 7.

Figure 7 – Recovery of NCMP After Exposure to CO_2

It can also recover from exposure to a fixed amount of CO_2 , as shown in Figure 8.

Figure 8 – Recovery of NCMP After Exposure to CO .

However, neither of these results should be taken to suggest that NCMP could withstand exposure to a continued supply of either CO or CO₂, as it would be if exposed to a reformat stream.

5.2 Results of Deliberations

First we considered how to overcome the limitation imposed by the gradual dissociation/disappearance of the Mg₃N₂ coating. Then we considered alternative coatings. Finally, we considered coatings for pellets as opposed to coatings for individual particles.

5.2.1 On Dealing with the Limited Life of Mg₃N₂ Coatings

- One could plan on replacing the coated particles every few weeks. We discarded this option for being impractical (though possible).
- One could also plan on re-coating the particles every few weeks, by fluidizing them *in situ* in a mixture of hydrogen and ammonia. This option we also discarded for being impractical (though possible).
- One could plan on introducing ammonia into the reformat at a concentration such that equilibrium would not favor dissociation of the Mg₃N₂ coating. Of course, this ammonia would have to be removed from the reformat upstream of any fuel cell. This option we also discarded for being impractical (though possible).
- It is even possible that reformat might already have ammonia in it (which is a concern shared by some in the fuel cell community). It is at least conceivable that this ammonia concentration is high enough to prevent the dissociation of the Mg₃N₂ coating. Again, this ammonia would have to be removed from the reformat upstream of any fuel cell.

Ammonia in the reformat is an issue that must be dealt with in fuel cell systems. It is not clear (at least to us) how much ammonia might be present, not how high a concentration of ammonia a fuel cell can tolerate. Whatever the concentration of ammonia in the reformat, the dissociation of the Mg₃N₂ coating will add to it. Some fuel cell system designers include a bed of activated charcoal upstream of the anode inlet for just this eventuality.

5.2.2 Alternative Coatings

The list of magnesium salts that would be both self-protective and inert to H₂O, CO and CO₂ is not a long one.

We did consider magnesium carbide, but could find no supplier of this compound. Those few references that we were able to locate in the literature spoke only to the theoretical properties of magnesium carbide, not to experimentally determined properties.

5.2.3 Coatings for Pellets

We considered using a thin sheet of palladium as a coating for a pellet made of magnesium powder (perhaps mixed with nickel or platinum powder). Such a coating might be applied by a hot isostatic pressing machine. We rejected this concept for the following reasons:

1. The ratio of palladium surface area to magnesium surface area would be too high, so that the kinetics would be limited by the mass transfer “bottleneck” represented by the limited surface area of the palladium.
2. It is not immediately apparent how to seal such a sheet hermetically. Folding the sheet will not suffice, and welding such a thin sheet may not even be possible with an electron beam welder.
3. The palladium sheet would not be nearly as well supported by the pellet as would a coating on an individual magnesium particle. The characteristic dimension of the unsupported span of the membrane over a pellet would be comparable to the diameter of the particles making up the pellet, whereas the characteristic dimension of the unsupported span of the coating on an individual magnesium particle would be comparable to the lattice spacing of the magnesium crystal.

All such deliberations terminated upon receipt of the information presented in the following section.

5.3 Results of Reading Current Literature

We noted the following on page 9 of the April, 1999 issue of *Hydrogen & Fuel Cell Letter*:

“Ergenics Announces Wet Hydrogen Cycling for Metal Hydrides

RINGWOOD, NJ – Hydride storage equipment maker Ergenics, Inc., here says it has developed a new technology that permits storage of wet hydrogen in its patented Hy-Stor line of metal alloys.

The company says it has achieved more than 7,000 cycles on 100% humidified hydrogen, dispelling “the myth that metal hydrides need ultra-pure hydrogen gas to achieve desirable performance goals,” the company said in a release.

Ergenics says its Hy-Stor materials can handle hydrogen gas streams “with extremely high levels of water vapor without any signs of alloy degradation or retardation.”

The technology can also store hydrogen with CO, CO₂ and nitrogen impurities: CO and CO₂ are not passed through, but nitrogen can move through the system, project manager David Tragna told H&FCL.

Ergenics isn't releasing any details on its patented purification system, but Tragna says it basically consists of an extra additive in the alloy, typically AB5 material.

Tragna said the first storage vessels incorporating the new technology have already been delivered to some customers, and the new technology will be available right away to others.

Ergenics currently offers six standard hydrogen storage units, with many of them customized for the fuel cell industry. Storage capacities range from 1 to 6,300 standard liters of hydrogen. Three popular models hold 50, 325 and 925 standard liters, respectively, with prices ranging from \$440 to \$2,200 each. Last June, the company announced it had sold its 300th storage vessel for fuel cells."

If that account truly reflects experimental fact, then there may be no point in pursuing our concept of coated particles any further. We reported same to DOE on April 21, 1999 and offered to test Ergenics' material independently, but that offer was declined.

6.0 Conclusions

We conclude as follows:

- A. The concept of a coating on a magnesium particle serving as a well supported hydrogen-permselective membrane is sound. Indeed, it has been demonstrated.
- B. Magnesium nitride can be made to coat magnesium particles through chemical vapor deposition within a fluidized bed.
- C. Magnesium nitride exhibits all of the properties we originally determined to be necessary for such a coating. That is,
 - 1. Mg_3N_2 is hydrogen-permselective.
 - 2. Mg_3N_2 does not react with the non-hydrogen species found in reformat.
 - 3. Mg_3N_2 -coated magnesium particles, when mixed with powdered dissociation catalyst, display adequate reaction kinetics.
 - 4. Neither magnesium particles nor the Mg_3N_2 coating is expensive.
 - 5. There is no evidence to suggest that the Mg_3N_2 coating detaches itself from the magnesium particle.
- D. However, magnesium nitride is not chemically inert to hydrogen in the absence of ammonia at temperatures typically used to hydride/dehydride magnesium.
- E. Ergenics has reportedly developed a hydridable metal that can tolerate H_2O , CO_2 and CO .

7.0 Recommendations

We recommend as follows:

1. DOE should seek to confirm that the Ergenics material can indeed tolerate H_2O , CO_2 and CO in the concentrations at which each appears in reformat and at the temperatures associated with hydriding dehydriding this material.
2. DOE should satisfy itself that the applications suggested herein for a reformat-tolerant hydridable material justify the development of such a material.
3. If the Ergenics material cannot be confirmed, and if DOE is satisfied that the applications for a reformat-tolerant hydridable material justify the development of same, then DOE should seek to determine if there is an acceptable method to circumvent the dissociation of magnesium nitride in the presence of hydrogen and in the absence of ammonia.