BULK-SCAFFOLDED HYDROGEN STORAGE AND RELEASING MATERIALS AND METHODS FOR PREPARING AND USING SAME

CROSS REFERENCE TO RELATED APPLICATION

This application is a Continuation-In-Part of Divisional application Ser. No. 11/941,549 filed 16 Nov. 2007, which in turn is a Divisional of U.S. application Ser. No. 10/778,997 filed 12 Feb. 2004, now granted as U.S. Pat. No. 7,316,788.

GOVERNMENT SUPPORT

This invention was made with Government support under Contract DE-AC0676RLO-1830 awarded by the U.S. Department of Energy. The Government has certain rights in the invention.

FIELD OF THE INVENTION

The present invention relates generally to materials and processes for storing hydrogen, and uses for same. More particularly, the present invention relates to bulk-scaffolded materials, compounds, materials, and combinations that provide storage and release of bulk quantities of hydrogen at lower release temperatures and faster release rates for operation of hydrogen-fueled on-board and off-board devices and applications.

BACKGROUND OF THE INVENTION

The Department of Energy (DOE) issued a challenge for hydrogen storage related technologies during 2003 to compliment existing programs on Hydrogen Production and Fuel Cell development. Part of the challenge involved proposed project milestones in calendar years 2010 and 2015 for the development of new materials and technologies relating to storing hydrogen for use as vehicle energy sources. Four technologies for storing hydrogen are under investigation in the technical art: (1) storage as simple metal hydrides, e.g., MgH_2, (2) storage on carbon materials, including single-walled carbon nanotubes, (3) storage as complex metal hydrides, e.g., $NaAlH_4$, and (4) chemical hydrogen storage, e.g. NH_xBH_x, where x=1 to 4. The technical developments related to chemical hydrogen storage technology are discussed further hereafter. Baitalow et al. have shown the potential for use of N—B—H compounds including ammonia borane (AB), NH_3BH_3, as a hydrogen storage material. Jaska et al. report hydrogen formation in AB is likely to occur by an intermolecular dimerization pathway as shown in reaction [1], although a two-step mechanism shown in reactions [2] and [3] is not ruled out:

$$2NH_3BH_3 \rightarrow NH_3BH_2—NH_2BH_3+H_2 \quad [1]$$

$$NH_3BH_3 \rightarrow NH_2{=}BH_2+2H_2 \quad [2]$$

$$2NH_2{=}BH_2 \rightarrow NH_3BH_2—NH_2BH_3 \quad [3]$$

Each step that forms a new B—N bond also forms hydrogen, as illustrated in reactions [4] and [5]:

$$NH_3BH_3+NH_3BH_2—NH_2BH_3 \rightarrow NH_3BH_2—NH_2BH_2—NH_2BH_3+H_2 \quad [4]$$

$$NH_3BH_3+NH_3BH_2NH_2BH_2—NH_2BH_3 \rightarrow NH_3BH_2—(NH_2BH_2)_2—NH_2BH_3+H_2 \quad [5]$$

Baitalow et al. further report at temperatures greater than 150° C., additional hydrogen may be released as illustrated in reactions [6] and [7]:

$$(NH_3BH_2NH_2BH_2—NH_2BH_3)_n \rightarrow (NH_3BH_2NH_2BH{=}NHBH_3)_n+H_2 \quad [6]$$

$$(NH_3BH_2NH_2BH{=}NHBH_3)_n \rightarrow (NH_3BH{=}NHBH{=}NHBH_3)_n+H_2 \quad [7]$$

However, it is well known in the art that release of hydrogen from neat AB occurs at temperatures at which undesirable side reactions occur thereby generating products that contaminate and decrease the purity of the released hydrogen for use as fuel. For example, formation of cyclic borazine, c-$(NHBH)_3$, an inorganic analog of benzene, is one such contaminating product reported by Wideman et al., illustrated in reaction [8]:

$$(NH_3BH{=}NHBH{=}NHBH_3)_n \rightarrow n(NHBH)_3+H_2 \quad [8]$$

Raissi et al. have reviewed data for hydrogen release from the neat solid AB. The reaction of NH_3BH_3 that yields $NH_3(BH_2—NH_2)_nBH_3$+free nH_2 releases hydrogen at temperatures near 115° C. in reactions that are comparatively slow and that again have a high potential for forming borazine. At even moderate reaction temperatures (e.g., >150° C.), borazine yields are significant. Borazine is damaging to fuel cells. Thus, its presence means the purity of released hydrogen remains questionable and thus unsuitable for use.

As the current state of the art shows, use of AB materials remains problematic due to: 1) relatively high reaction temperatures required for hydrogen release, 2) slow rates for release of hydrogen, and 3) presence of contaminants like borazine that contaminate the hydrogen released from the source materials that complicate their use as a fuel source.

Accordingly, there remains a need to: 1) decrease temperatures at which hydrogen is released to meet proposed guidelines for bulk hydrogen fuel storage and use; 2) improve rates for hydrogen release; and 3) minimize side reactions that generate undesirable and contaminating products thereby increasing the purity of hydrogen that is available as a fuel.

SUMMARY OF THE INVENTION

The present invention provides materials, methods and mechanisms for storing and releasing hydrogen in a way that produces greater rate yields at lower temperatures than are found in the prior art while simultaneously preventing undesired side reactions and providing released hydrogen with sufficient purity so as to allow for various hydrogen energy based applications. The materials of the present invention provide greater capacities for storage and release of hydrogen in a pure state and thus have the potential to serve numerous industrial applications wherein high hydrogen storage and usage demands may be met, including, but not limited to, next generation fuel cells and hydrogen sources, applicable to uses in the automobile industry and elsewhere.

In one embodiment the invention is a bulk-scaffolded hydrogen storage and releasing material, made up of a preselected ratio of at least one hydrogen storage and releasing compound combined with a porous support to form a bulk-scaffolded hydrogen storage that releases a bulk quantity of hydrogen at a greater rate, a lower temperature, than the hydrogen storage compound alone. In one embodiment of the invention the hydrogen storage and releasing compound comprises about 30% to about 99% of said material by weight. In another embodiment of the invention the porous support comprises between about 70% to about 1% of said material by weight. This porous support can have pores in a variety of