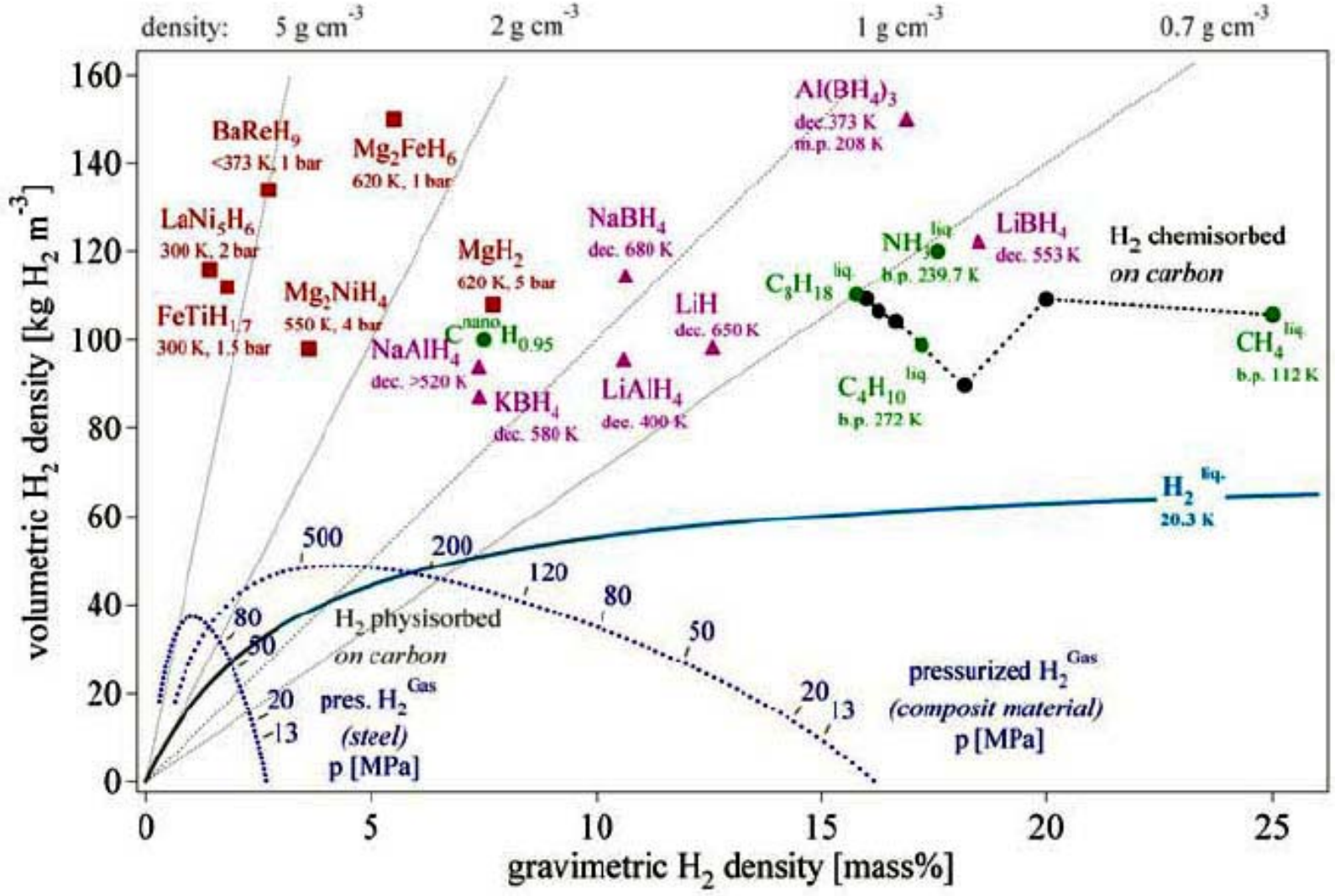
Implementation - Liaison Committee
Hydrogen Storage Scoping Paper

Background

The proposed areas of international collaboration shall focus on novel storage technologies, which are currently not yet near commercialization and do have the potential to meet the long term goals required for a viable global hydrogen economy.

The proposed R&D areas also take into consideration the various international efforts already underway, such as the International Energy Agency's (IEA) Hydrogen Implementing Agreement (hydrogen storage activities, currently through Annex 17).

Background


density: 5 g cm-3
2 g cm-3
1 g cm-3
0.7 g cm-3
volumetric H2 density [kg H2 m-3]
gravimetric H2 density [mass%]
BaReH9
<373 K, 1 bar
Mg2FeH6
620 K, 1 bar
LaNi5H6
300 K, 2 bar
FeTiH1.7
300 K, 1.5 bar
Mg2NiH4
550 K, 4 bar
MgH2
620 K, 5 bar
NaAlH4
dec. >520 K
Cnano H0.95
KBH4
dec. 580 K
NaBH4
dec. 680 K
LiH
dec. 650 K
LiAlH4
dec. 400 K
Al(BH4)3
dec. 373 K
m.p. 208 K
NH3 liq
b.p. 239.7 K
LiBH4
dec. 553 K
C8H18 liq
C4H10 liq
b.p. 272 K
H2 chemisorbed
on carbon
CH4 liq
b.p. 112 K
H2 liq.
20.3 K
500
200
120
80
50
20
13
H2 physisorbed
on carbon
pres. H2 Gas
(steel)
p [MPa]
pressurized H2 Gas
(composit material)
p [MPa]

Background

To avoid duplication of current work and to focus on areas with significant technical challenges, the following key areas are proposed:

- Solid state (or liquid state) systems that are truly reversible, such as metal hydrides and carbon, and
- Chemical hydrogen storage systems, such as chemical hydrides, which must be regenerated off-board.

In addition to a focus on the above hydrogen storage technologies, global collaboration on two additional crosscutting topics is proposed:

- Standardized testing of materials and systems for hydrogen storage capacities, and
- Systems analyses which include life cycle, efficiency, safety and environmental impact analyses.

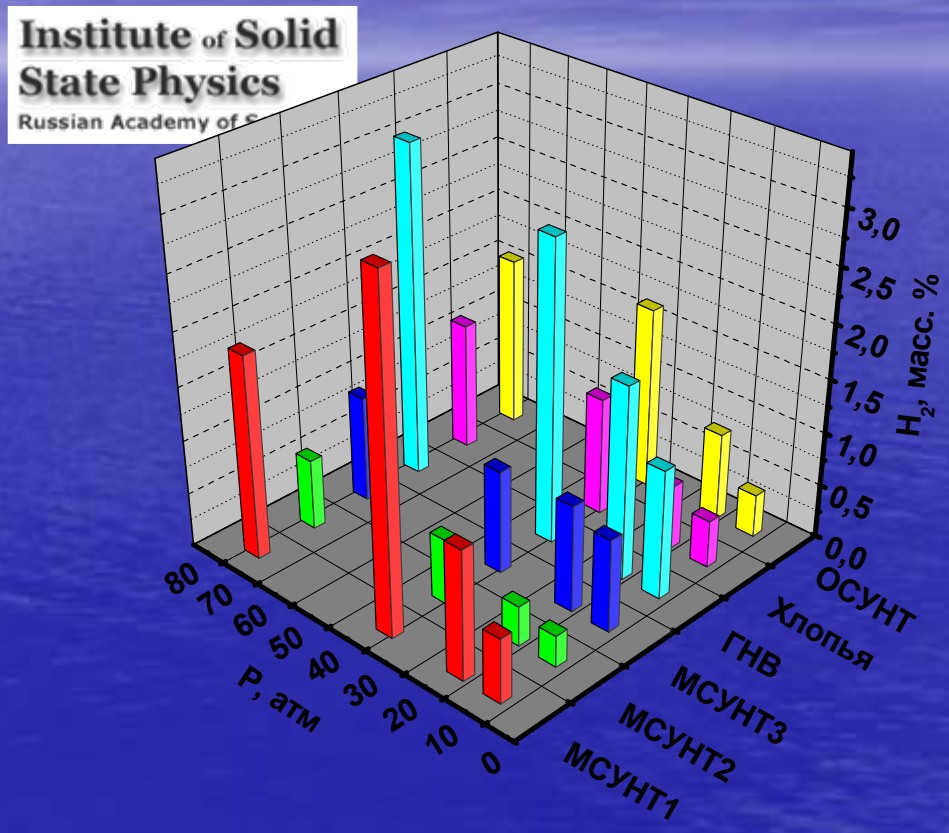
Hydrogen Storage Technical Barriers: General

- **Weight and Volume**. The weight and volume of hydrogen on-board storage systems are presently too high, resulting in inadequate vehicle range compared to conventional petroleum fueled vehicles.
- **Efficiency.** Energy efficiency is a challenge for all hydrogen storage approaches.
- **Durability**. Durability of hydrogen storage systems is inadequate. Materials and components are needed that allow hydrogen storage systems with a lifetime of 1500 cycles
- **Refueling Time**. Refueling times are too long.
- **Safety, Codes & Standards**. Standardized hardware and operating procedures, applicable codes and standards, and ensuring that storage systems meet safety requirements and crash-worthiness, are required
- **Life Cycle, Environmental Impact, and Efficiency Analyses**. There is a lack of analyses of the full life-cycle cost, environmental impact, and efficiency for hydrogen storage systems.
- **Cost**. The cost of hydrogen storage systems is too high.

Hydrogen Storage Technical Barriers: Reversible Solid-State Material Storage Systems

- **Hydrogen Capacity and Reversibility.**

Hydrogen capacity and reversibility are inadequate at practical operating temperatures and pressures and within refueling time constraints. Adequate cycle life of these systems has not been demonstrated.

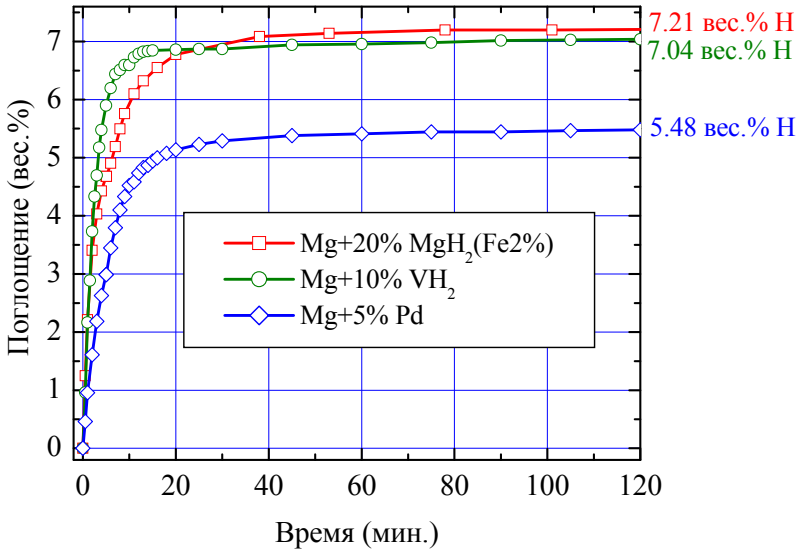


Reversible capacity of carbon nanostructures (nanotubes, nanofibers, nanoflakes) at 20°C

Hydrogen Storage Technical Barriers: Reversible Solid-State Material Storage Systems

- **Kinetics: Lack of Understanding of Hydrogen Physisorption and Chemisorption.**

  Fundamental understanding of hydrogen physisorption and chemisorption processes is lacking. Improved understanding and optimization of absorption/desorption kinetics is needed to optimize hydrogen uptake and release and to provide sufficient flow rates of hydrogen for vehicle use.

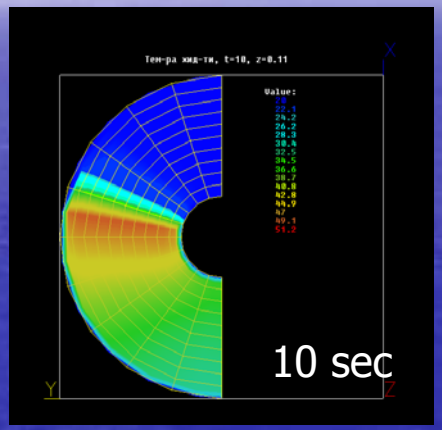


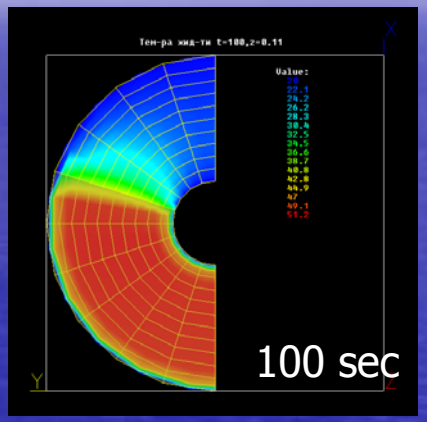
Pure Hydrogen
Pressure 1.3 MPa
Temperature 300°C

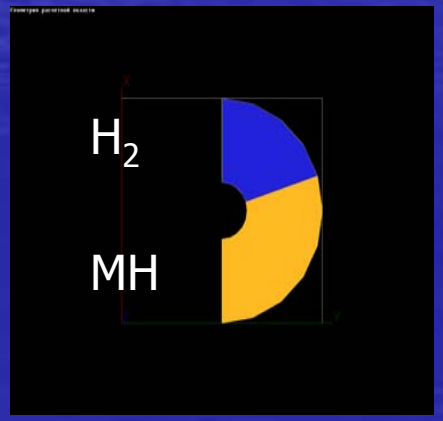
Hydrogen Storage Technical Barriers: Reversible Solid-State Material Storage Systems

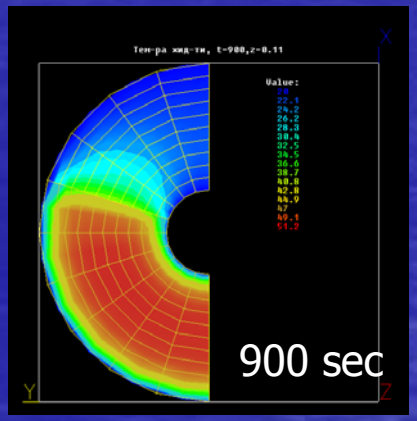
- **Heat and mass transfer in storage media.**

  Understanding of heat and mass transfer peculiarities in micro- and nano-structured materials at sorption/desorption processes with big volumetric and thermal effects is lacking. Adequate mathematical models to optimize reversible solid-state material hydrogen storage systems are needed.









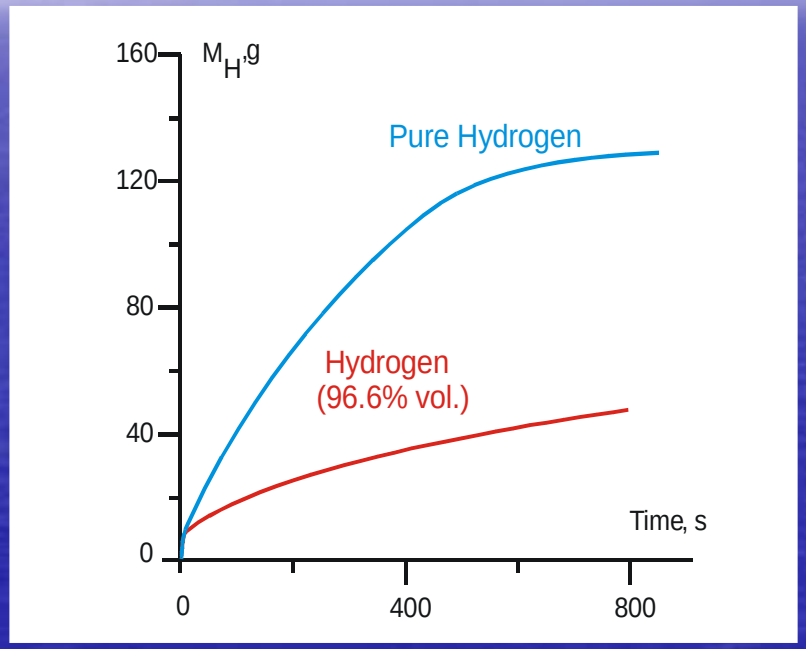
ИВТАН

Temperature fields inside MH reactor during sorption

Hydrogen Storage Technical Barriers: Reversible Solid-State Material Storage Systems

- **Hydrogen Purity.**

  Non-absorbable impurities dramatically decrease efficiency of hydrogen systems affecting kinetics, heat and mass transfer, refueling time and energy conversion efficiency in fuel cells.



ИВТАН

Sorption of pure and impure Hydrogen.
Results of calculations

Hydrogen Storage Technical Barriers: Reversible Solid-State Material Storage Systems

- **Test Protocols and Evaluation Facilities.**

  Standard test protocols and independent facilities for evaluation of hydrogen storage materials are lacking.

Hydrogen Storage Technical Barriers: Reversible Solid-State Material Storage Systems

- **Dispensing Technology.**

  Dispensing technology has not been defined.

Hydrogen Storage Technical Barriers: Chemical Hydride Storage Systems

- **Regeneration Processes for Irreversible Systems**. Low-cost, energy-efficient regeneration processes for irreversible systems have not been established. Cost effective regeneration processes need to be identified and developed. Full life-cycle analyses need to be performed to understand cost, efficiency, safety and environmental impacts.

- **By-Product Removal**. The refueling process is potentially complicated by byproduct removal. System designs must be developed to address the byproduct issue.

Proposed Areas of International Research, Development, and Collaboration

- For metal hydrides, despite the significant advances in recent years, there is still no technology that meets the weight requirement for vehicles. New reversible solid materials with hydrogen storage capacities up to 4% at $t \leq 100^{o}C$ and $\geq 5\%$ at $t \leq 400^{o}C$ should be developed.
- Innovation beyond the current state-of-the-art in complex metal hydrides (and beyond IEA activities) is sought in order to attain truly reversible systems that also meet the weight, volume, safety and cost targets for vehicles.
- Although significant effort is underway through the IEA on carbon materials (such as carbon nanotubes), breakthrough concepts to meet required storage capacities using low cost carbon-based and carbon-metal composed materials would be of interest.
- For chemical storage, a key issue is whether reclaiming and regenerating the spent fuel byproduct off-board is viable in terms of overall efficiency, environmental impact, safety and cost.
- Investigations of heat and mass transfer in micro- and nano-structured materials at sorption/desorption and development of adequate mathematical models to optimize reversible solid-state material hydrogen storage systems are needed.

Proposed Areas of International Research, Development, and Collaboration

- Integrated hydrogen purification and storage systems should be developed.
- In all cases, both fundamental R&D and systems level engineering are required to achieve the storage capacities to meet the volume, weight, safety and cost constraints of vehicles.
- Standardized test and measurement protocols should be established.
- In terms of systems analyses, it is imperative that the complete hydrogen storage system within the context of the infrastructure required for a hydrogen economy be evaluated. Both on-board and off-board storage systems must be evaluated in terms of environmental impact, overall energy efficiency, safety and cost, from a complete life cycle standpoint.
- Finally, a specific recommendation to promote international collaboration beyond the scope of the IEA and advance the current status of hydrogen storage technologies is to organize an International Workshop on Hydrogen Storage

MILESTONES

- The International Workshop on Hydrogen Storage, **June 2005 - Italy.**

The Workshop would provide a framework for providing baseline information on various technologies, tracking worldwide progress, and identifying critical areas that would benefit from leveraging the efforts of multiple countries.