PURPOSE

Task 22 addresses hydrogen storage in solid materials. The specific goals and objectives for research on hydrogen storage materials in Task 22 are:

- Develop a reversible or regenerative hydrogen storage medium fulfilling international targets for hydrogen storage.
- Develop the fundamental and engineering understanding of hydrogen storage by various hydrogen storage media that have the capability of meeting Target A.
- Develop hydrogen storage materials and systems for use in mobile and stationary applications and also other potential energy related applications, for example in batteries.

STATUS OF THE TECHNOLOGY

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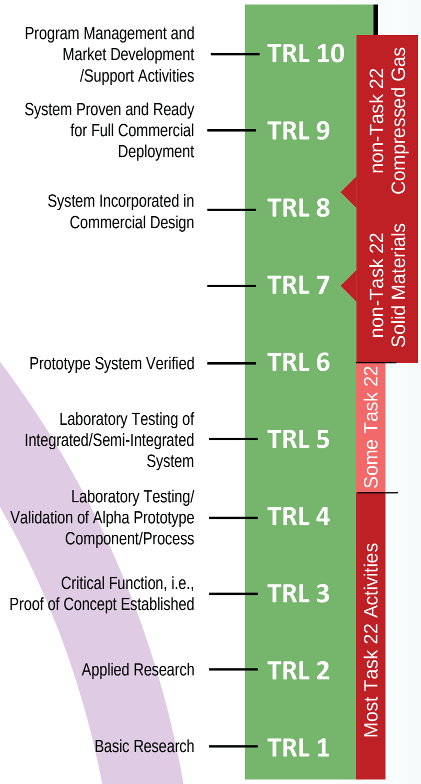
Hydrogen storage remains an undisputed problem that is considered by many to be the most technologically challenging aspect of achieving a hydrogen-based economy. Furthermore, it is clear that compressed or liquid hydrogen will never meet the long-term goals related to gravimetric and volumetric capacities for hydrogen storage in vehicles. Hydrogen storage in solid materials constitutes another storage alternative with potential satisfactory properties. However, in spite of the significant achievements related to hydrogen storage in solid materials during the last decade, further progress is still needed to fulfill the international goals for applications in vehicles, in particular with respect to gravimetric and volumetric capacities, temperature and pressure for hydrogen uptake and release and kinetics of these processes. Further development of materials is also crucial for hydrogen storage in stationary and marine applications. Such research efforts will require new materials and solutions, as well as improvements in current technologies and materials. Demonstration of solid storage systems is needed for general public acceptance.

TECHNOLOGY READINESS LEVEL (TRL)

The projects in Task 22 cover TRL 1 to TRL 4: Basic research (TRL 1), Applied research (TRL 2), Critical Function, i.e. Proof of Concept Established (TRL 3) and Laboratory Testing/Validation of Alpha Prototype Component/Process (TRL 4), respectively. The majority of the activities may be classified at TRL 2 and TRL 3.



TASK 22

FUNDAMENTAL AND APPLIED HYDROGEN STORAGE MATERIALS DEVELOPMENT

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VITAL STATISTICS

Term

Phase 1: 2006-2009

Phase 2: 2009-2012

Members (17 countries)

Australia
Canada
Denmark
France
Germany
Greece
Iceland
Italy
Japan
Korea
Lithuania
Norway
Netherlands
Sweden
Switzerland
United Kingdom
USA

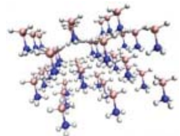
Expert Participants (54 Experts)

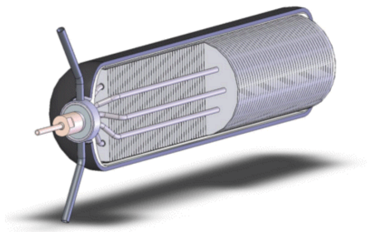
C. Ahn, USA
E. Akiba, Japan
A. Albinati, Italy
M. Allendorf, USA
Y. Andersson, Sweden
D. Anton, USA
T. Autrey, USA
M. Baricco, Italy
J. Bellosta von Colbe, Germany
D. Book, UK
C. Brown, USA
C. Buckley, Australia
A. Burrell, USA
R. Cantelli, Italy
Y. Chabal, USA
R. Chahine, Canada
D. Chandra, USA
Y.W. Cho, Korea
B. Dam, Netherlands
B. David, UK
P. de Rango, France
M. Dornheim, Germany
M. Fichtner, Germany
D. Fruchart, France
J. Graetz, USA
E. Gray, Australia
K. J. Gross, USA
Z. X. Guo, UK
B. C. Hauback, Norway
M. Hirscher, Germany
J. Huot, Canada
T. R. Jensen, Denmark
C. M. Jensen, USA
Y. Kojima, Japan
N. Kuriyama, Japan
M. Latroche, France
S.-Y. Liu, USA
D. Milcius, Lithuania
D. Mosher, USA
D. Noréus, Sweden
S. Olafsson, Iceland
S.-I. Orimo, Japan
P. Prosini, Italy

FRAMEWORK SUMMARY

Task 22 started a three year term in December 2006. The Executive Committee of IEA HIA approved a three years extension from December 2009 to November 2012. The task is open for a broad spectrum of project types:

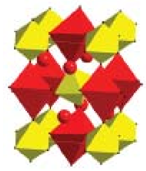
- experimental
- engineering
- theoretical
- modeling
- safety aspects of hydrogen storage materials





The following classes of materials are included:

- reversible metal hydrides
- regenerative hydrogen storage materials (chemical hydrides)
- nanoporous materials



Task 22 is built on projects with international collaboration strongly encouraged. A project plan is prepared for each project. Task 22 consists of the following projects (with the project leader in parentheses):

- Light metals and porous materials for hydrogen storage (C. Buckley, Australia)
- In-situ studies of hydrogen storage materials with neutrons and X-rays (E. Gray, Australia)
- Effect of severe plastic deformation on hydrogen storage behavior (J. Huot, Canada)
- Synthesis and characterization of light metal hydrides and nanoporous materials (T. R. Jensen, Denmark)
- Integrated computational and experimental methods for thermodynamic predictions and kinetic analysis (T. Vegge, Denmark)
- TM and RE intermetallics based hydrides, from fundamental to processes and storage units (D. Fruchart, France)
- Composite materials combining metallic compounds and porous materials for the chemical or electrochemical storage of hydrogen (M. Latroche, France)
- Kinetic optimization of $LiBH_4/MgH_2$ and $Ca(BH_4)_2/MgH_2$ Reactive Hydride Composites (M. Dornheim, Germany)
- Synthesis and characterization of new tetrahydroborate compounds and nanoscale hydrides (M. Fichtner, Germany)
- Hydrogen physisorption on MOFs (M. Hirscher, Germany)
- Synthesis and characterization of metal doped carbons (T. A. Steriotis, Greece)
- Fundamental and applied hydrogen storage materials development of composite Mg:C materials: Using thin films and post composite processing of ball milled material (S. Ólafsson, Iceland)
- Hydrogen storage in nanostructured complex hydrides, molecular compounds and metal alloys (A. Albinati and R. Cantelli, Italy)
- Experimental and theoretical studies of hydrogen storage materials (M. Baricco, Italy)
- Experimental and theoretical studies on hydrogen storage materials (M. Baricco, Italy)
- Hydrogen storage devices based on NaBH4 (P. Prosini, Italy)
- Atomic scale characterization of hydrogen storage materials (metal hydrides, nanoporous materials, clathrates, MOFs) by optical spectroscopy and neutron scattering techniques (M. Zoppi, Italy)

- Synthesis and characterization of novel metal hydrides (E. Akiba, Japan)
- Basic research on non-metallic hydrogen storage materials (Y. Kojima, Japan)
- Synthesis under high-pressure hydrogen atmosphere (N. Kuriyama, Japan)
- Development of Light-Weight and Compact Hydrides (S.-I. Orimo, Japan)
- Synthesis and characterization of complex alloy hydrides (Y. W. Cho, Korea)
- Development of nanocrystalline metal hydrides using vapour deposition technologies (D. Milcius, Lithuania)
- Synthesis, structural characterization and stability of complex hydrides (B. C. Hauback, Norway)
- Analysis of interface effects in light-weight metal hydride thin films using hydrogenography (B. Dam, Netherlands)
- Metastable lightweight hydrides (D. Noréus, Sweden)
- Syntheses and characterization of hydrogen absorbing compounds based on magnesium, aluminium and 3d transition metals (Y. Andersson, Sweden)
- Stability and reversibility of borohydrides for hydrogen storage (A. Züttel, Switzerland)
- Hydrogen storage in borohydrides and light-metal hydrides (D. Book, UK)
- Synthesis, structure, stability and simulation of novel complex hydrides (B. David, UK)
- Tailoring reaction routes for metal and complex metal hydrides (Z. X. Guo, UK)
- Neutron scattering and ab initio investigations of hydrogen storage materials (D. K. Ross, UK)
- Porous materials IEA collaboration (G. Walker, UK)
- Multicomponent hydride systems (G. Walker, UK)
- High pressure ambient temperature hydrogen storage adsorption (C. Ahn, USA)
- Controlled synthesis of metal hydride nanoclusters (M. Allendorf, USA)
- Chemical hydrogen storage (T. Autrey, USA)
- Structure and dynamics of hydrogen in physisorbent systems (C. Brown, USA)
- Metal amidotrihydroborates (A. Burrell, USA)
- Novel theoretical and experimental approaches for understanding and optimizing molecule-sorbent interactions in metal organic framework materials (Y. Chabal, USA)
- Amorphous alloy membranes prepared by melt-spin methods for long-term use in hydrogen separation applications (D. Chandra, USA)
- Regeneration of kinetically stabilized hydrides (J. Graetz, USA)
- International standardized practices and materials development for hydrogen storage (K. J. Gross, USA)
- Novel borohydrides for hydrogen storage (C. M. Jensen, USA)
- Hydrogen storage by novel CBN heterocycle materials (S.-Y. Liu, USA)
- Neutron metrology of hydrogen in bulk and nanoconfined metal-hydride and complex-hydride systems (T. Udovic, USA)
- Exploration of lightweight borohydrides for hydrogen storage (J.-C. Zhao, USA)
- Development and characterization of novel hydrogen storage materials (R. Zidan, USA)
- Engineering/Applied hydrogen storage:
  - Fundamental Studies and Chemical & Thermal Modeling in Hydrogen Storage Systems (D. Anton, USA)
  - Hydrogen Storage Solutions for Stationary and Mobile Applications: From

D. K. Ross, UK
T. Steriotis, Greece
S. Tsunokake, Japan
T. Udovic, USA
T. Vegge, Denmark
G. Walker, UK
V. A. Yartys, Norway
J. C. Zhao, USA
R. Zidan, USA
M. Zoppi, Italy
A. Züttel, Switzerland

2011 Meetings

January 16-20
Fremantle, Australia
September 4-8
Copenhagen, Denmark

Materials to Systems (V. Yartys, Norway)

- Sorption Systems and Materials for On-Board Hydrogen Storage (R. Chahine, Canada)
- Development of Combined Heat and Hydrogen Storage Systems Based on Low-Cost Metal Hydrides (Y.-W. Cho, Korea)
- System Engineering for Materials Based Hydrogen Storage (D. Mosher, USA); Off-Grid and Remote-Area Electricity Supply With Integrated Hydrogen Storage (E. Gray, Australia)
- Hydrogen Storage Systems Based On Complex Hydrides (M. Fichtner, Germany)
- Design and Testing of High Capacity Alane and Chemical Hydride Based Hydrogen Storage Systems (C.M. Jensen, USA)
- Research, Development and Safety Assessment on Metal Hydride Tanks (S. Tsunokake, Japan)
- Large Scale MgH2 Tanks for Stationary Applications (P. de Rango, France)
- Hydrogen Storage Tank Development and System Integration Based on High Capacity Solid State Storage Material (J. Bellosta von Colbe, Germany)

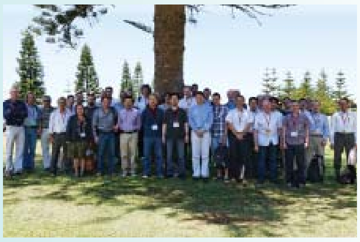


Figure 1: Participants at the Task 22 meeting in Fremantle, Australia 16–20 January 2011.

Figure 2: Participants at the Task 22 meeting in Copenhagen, Denmark 4–8 September 2011.

Figure 3: The Carlsberg Academy (Niels Bohr's house) --September 2011.

MEMBERS

Fifty-four (54) Experts from 17 countries participate in Task 22 for a total effort of about 64 person years/year. (Total Participation level has maintained this level since initiation of the task in 2006)

ACTIVITIES AND RESULTS IN 2011

PROGRESS AND ACCOMPLISHMENTS

Two Task 22 Experts meeting was held in 2011:

- The eighth Task 22 meeting in Femantle in Australia, January 16–20, had 43 participants (Figure 1)
- The ninth Task 22 meeting in Copenhagen, Denmark, September 4–8, had 63 participants (Figure 2)

The majority of the projects were presented and discussed in the two meetings with emphasis on new and unpublished results. Task 22 is the major forum for international activities in this field, and a number of international collaborative efforts have been established via active participation in the meetings. The progress in 2011 is particularly related to:

- New results for nanoporous materials. This includes new compounds and significant efforts to understand chemisorptive (spillover) materials.
- Novel metal hydrides. Possible reversible compounds based on the elements boron, magnesium and nitrogen and mixtures/composites of different hydrides have been investigated. A major emphasize is on studies of complex hydrides based on boron, so-called borohydrides. There are also efforts on regenerative hydrides including aluminum and boron-nitrogen hydrides.
- 'Nano-hydrides' for hydrogen storage. Thermodynamics and conditions for hydrogen

reaction rates can be modified by reducing the particle size of the metal hydrides into the nano-size range or by nanoconfinements.

- Application of hydrogen storage materials. The Engineering and Applied hydrogen storage project has participation from 11 Experts. This project addresses in particular solid storage for different kinds of vehicles and stationary use.

OUTREACH AND COMMUNICATION

During the first four years of Task 22, a total of 850 articles were published in international peer-review journals. Some 1150 presentations were given in national and international meetings/conferences and 50 patents/patent applications related to work performed in Task 22 were filed. The number of additional articles and presentations in 2011 are estimated to be 250 and 300, respectively.

The list of publications and one-page annual progress reports for each of the projects in Task 22 are found on the website: www.hydrogenstorage.org.

FUTURE WORK

ACTIVITIES AND /OR TARGETS FOR 2012

There will be two Task 22 meetings in 2012, the first in Heidelberg in Germany in May and the second, which will be the final Task 22 meeting, in Kyoto, Japan in October. The meeting in Heidelberg will have duration of four days and consist of presentations showing achievements in the different projects and broader discussion related to challenges and general progress in the field. There will be efforts to further strengthen international collaboration relating to both fundamental and applied hydrogen storage development. The last meeting in Kyoto will focus on summary of achievements and future prospects for hydrogen storage materials in a new task.

ACTIVITIES AND/OR TARGETS BEYOND 2012

Task 22 will end in November 2012, and a target beyond 2012 is to establish a new hydrogen storage Task in IEA HIA. Plans for a new task will be discussed in the two Task 22 meetings in 2012.

R&D CHALLENGES

Storage of hydrogen remains as one of the major challenges related to the introduction of hydrogen for both mobile and stationary applications. There has been significant progress within Task 22. However, for mobile applications in particular, solid materials do not fulfill all requirements with respect to weight and volume of storage system, the conditions (temperature and pressure) for hydrogen storage and kinetics of the hydrogen uptake and the release. Use of solid storage for stationary storage appears to be more feasible in the shorter term, but materials still need optimization. Furthermore, a major focus on new ideas and novel compounds will continue as well.