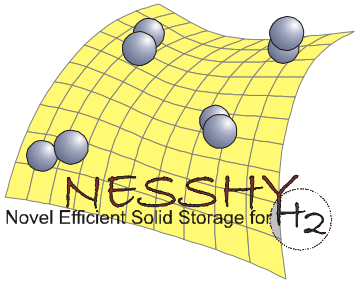
NESSHY

“Novel Efficient Solid Storage for Hydrogen”



IP SES6-CT-2006-518271

HySIC

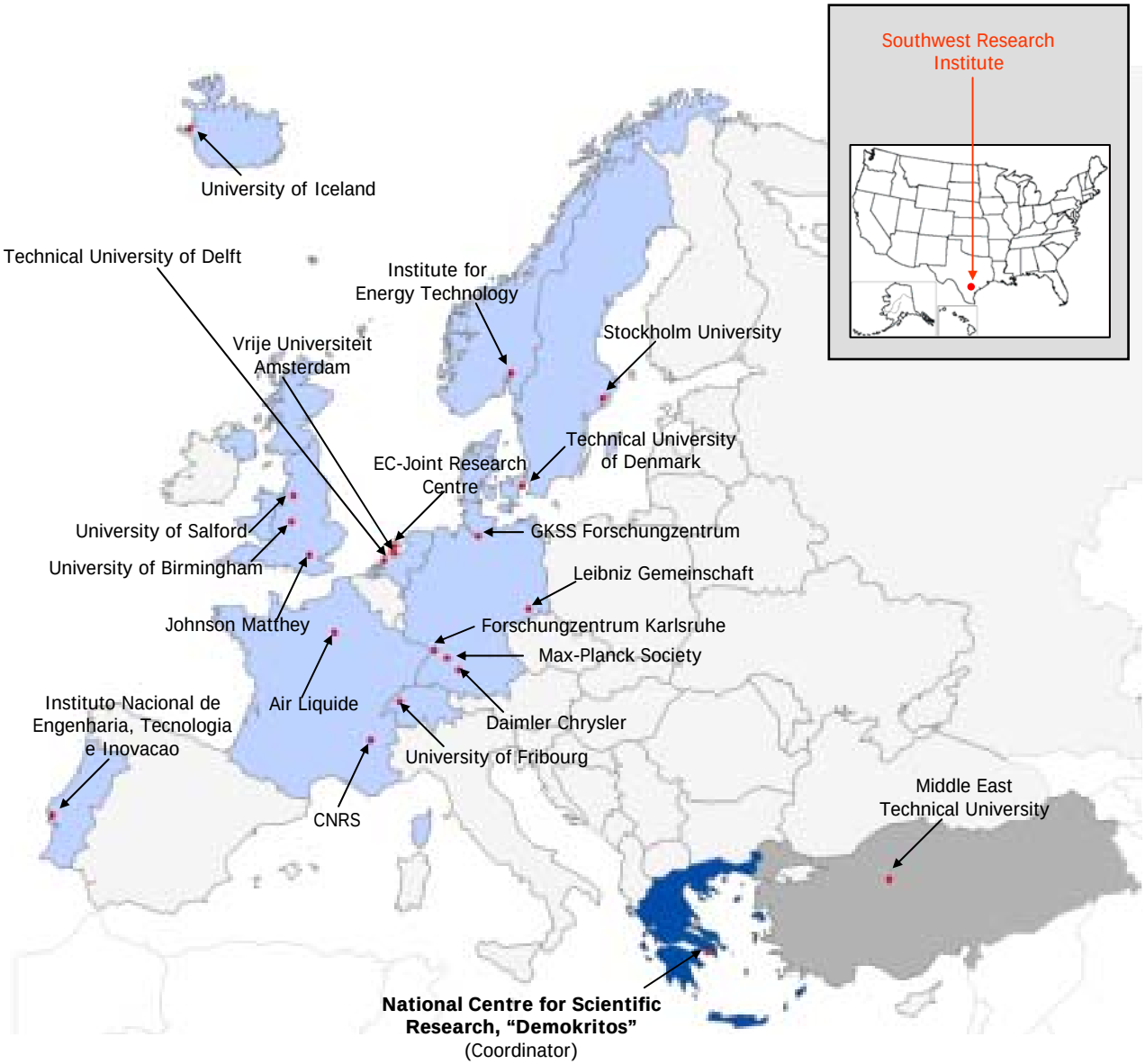
Enhancing International Cooperation in running FP6 Hydrogen Solid Storage activities

SES6 038941

Thanos Stubos
National Center for Scientific Research «Demokritos»
Athens - Greece

General facts

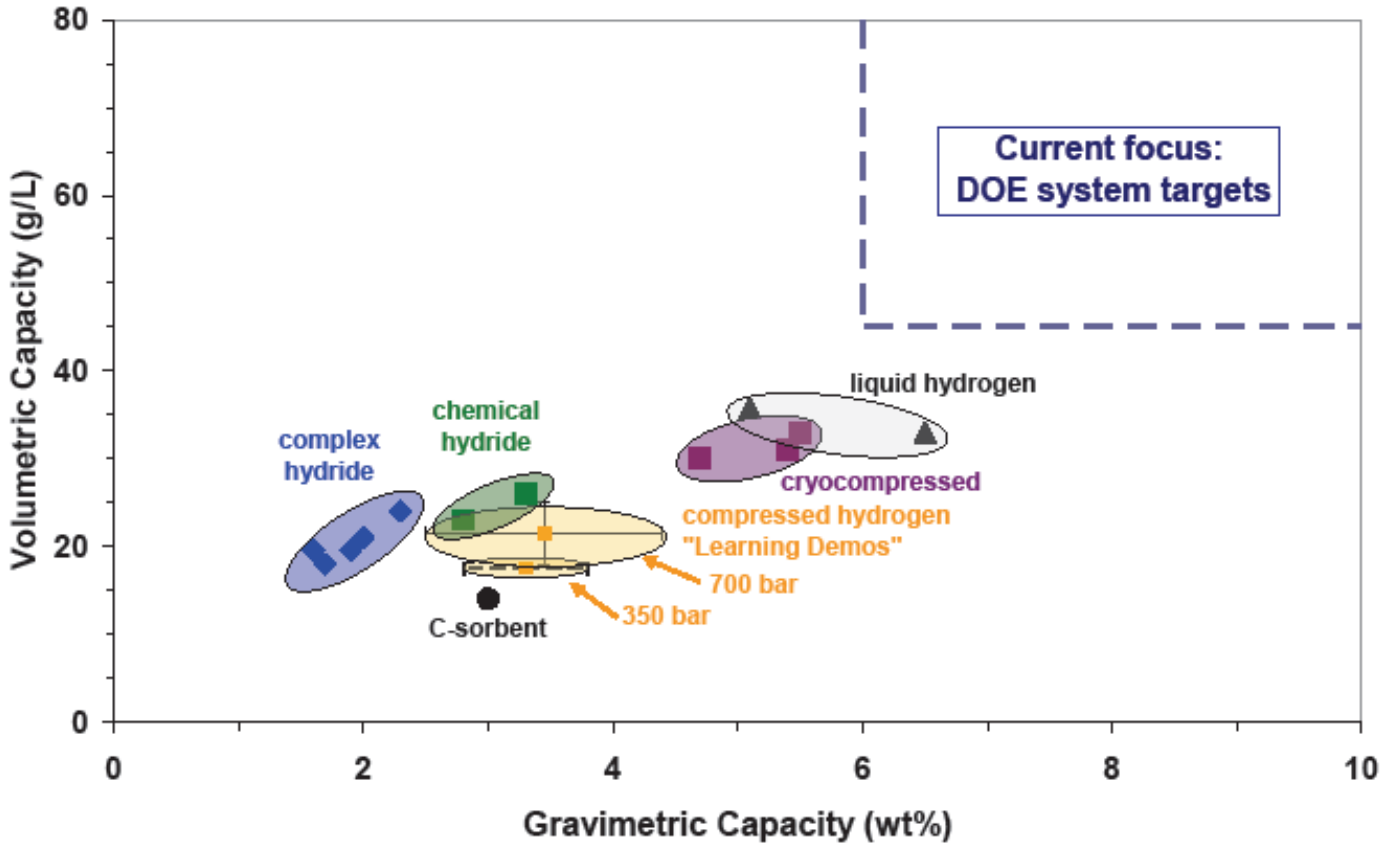
- **Co-ordinator: NCSR Demokritos (EL)**
- **Duration:1.1.2006 – 31.12.2010 (5 years)**
- **Budget: M€ 11.3**
- **EC contr.: M€ 7.5**
- **22 partners from 12 European countries and USA (1 OEM, 19 research institutes, 2 industrial companies)**



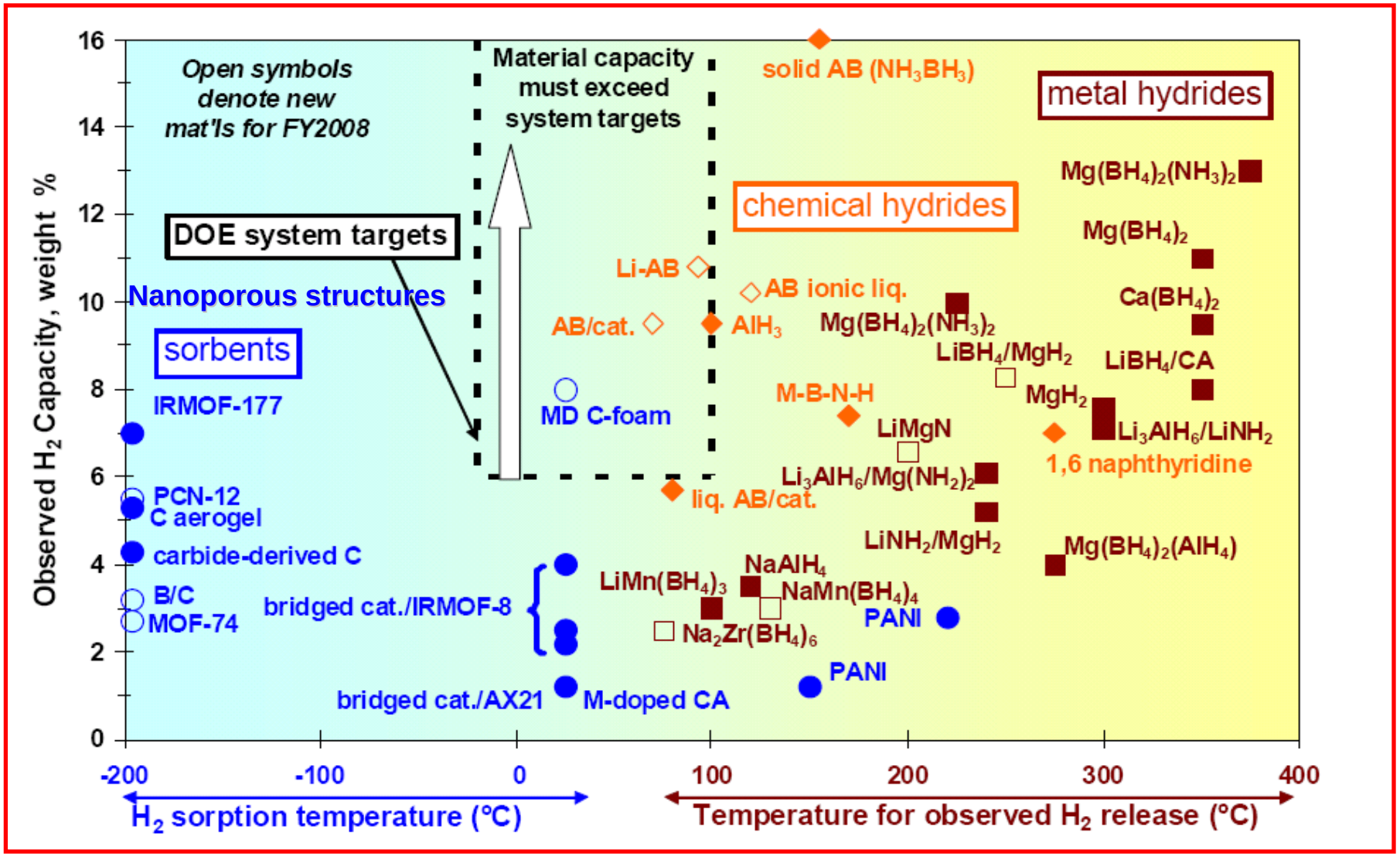
Challenges

- Vehicles are being designed by OEMs that can achieve > 300 miles
  - 350 or 700 bar
  - 1 to 4 tanks
  - Specified range from
    ~200 to > 350 miles
- But performance, space on-board and cost are still challenges for mass market penetration…
- Is there a low pressure alternative?

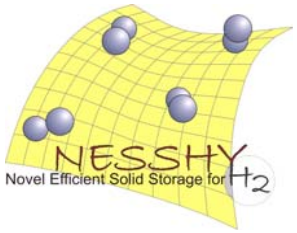
Current Status
No Technology meets targets



Materials State of the art

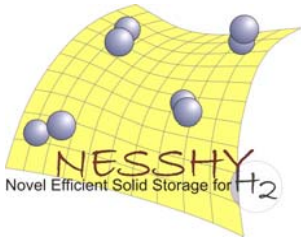


DOE: G. Thomas (2007), G. Sandrock (2008)



Present Status of H-Solid Storage Technology

- ✓ **Hydrogen solid storage:**
  - **Importance of breakthroughs**
  - **Continuation of funding NECESSARY as also clearly acknowledged at DoE Review Meeting (June ’08)**

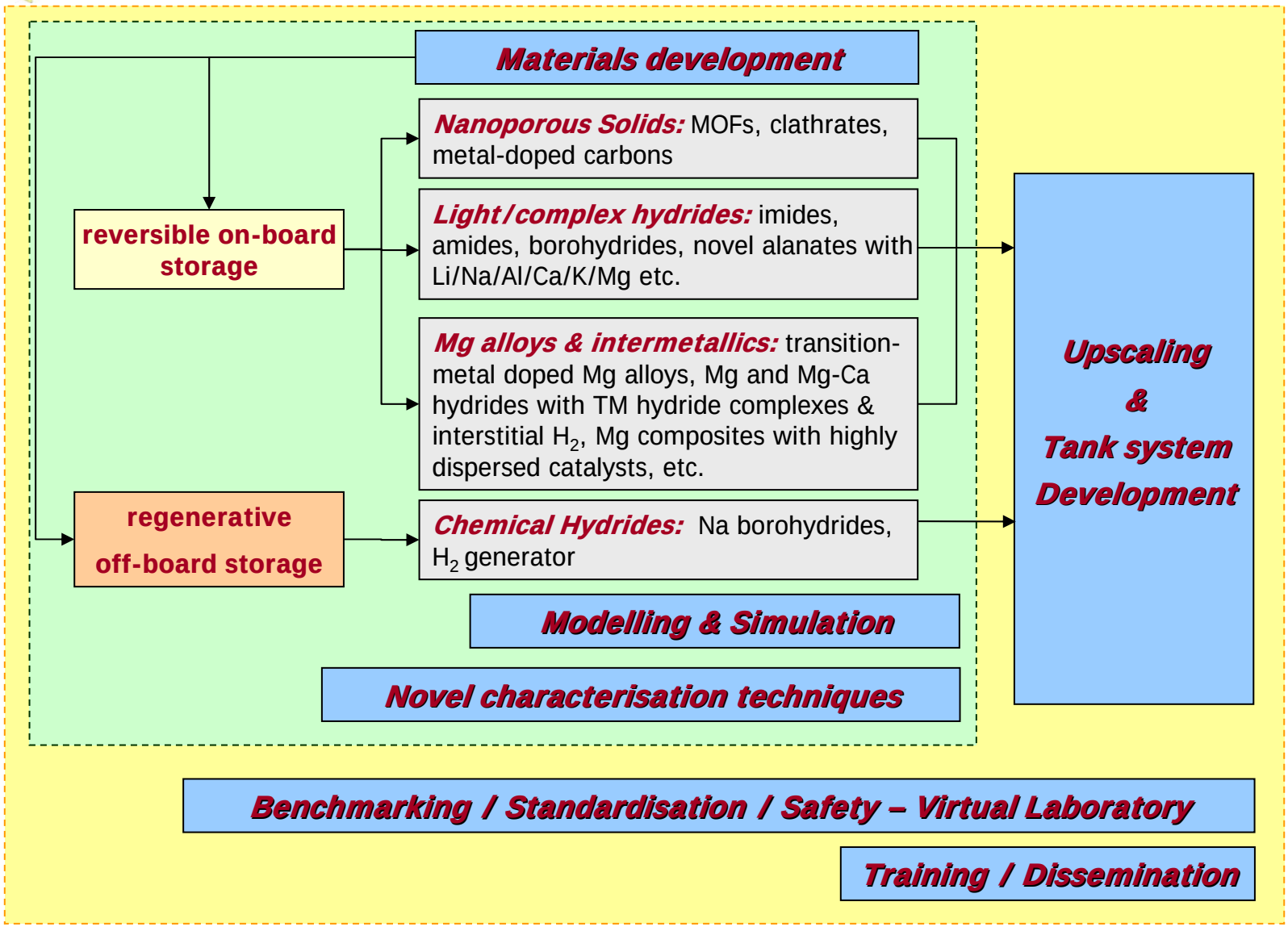


NESSHY vision

NESSHY *aims at* advancing the current state of hydrogen storage in solid materials, with respect to

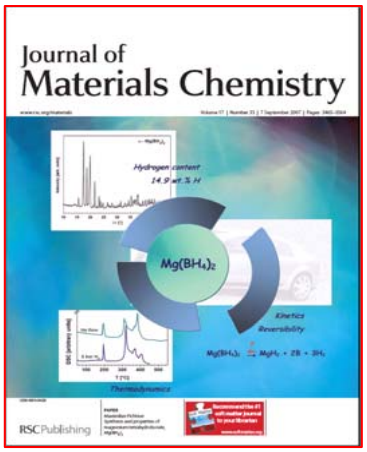
- ✓ **novel materials**
- ✓ **enhanced understanding of the physical mechanisms involved**
- ✓ **novel analytical and characterisation tools and measurement techniques**
- ✓ **standardisation, testing protocols (virtual laboratory)**
- ✓ **advanced numerical methods for optimal material & storage design**
- ✓ **upscaling the production processes of promising materials**
- ✓ **design and testing of storage tank systems**

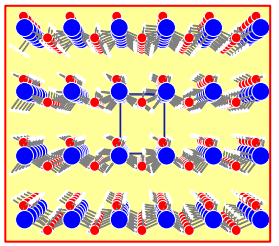
NESSHY workplan



NESSHY Highlights - Materials

✓ **Novel synthesis of magnesium tetrahydroborate, $Mg(BH_4)_2$ → potential for H_2 storage (14.9 mass % H & suitable thermodynamic properties)**

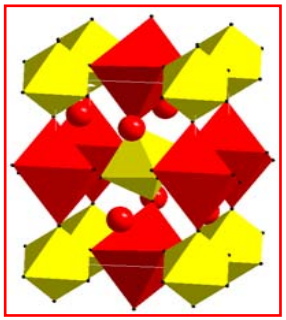




J. Mater. Chem., **17** (2007) 3496–3503

✓**Mixed alanates → patent applications:**

- **Detailed studies of a wide range of systems**
- **Changed thermodynamics (reduction of reaction enthalpy towards relatively fast reversible H_2 storage) by substitution of hydrogen atoms with fluorine in $NaAlH_4$**

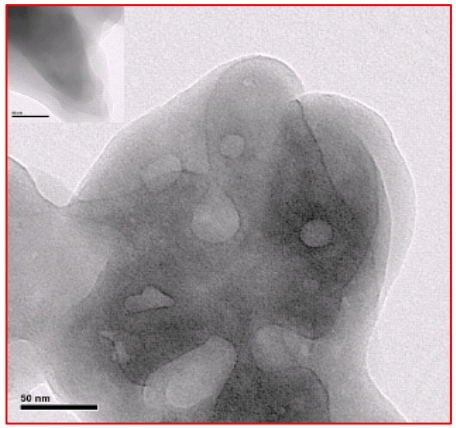


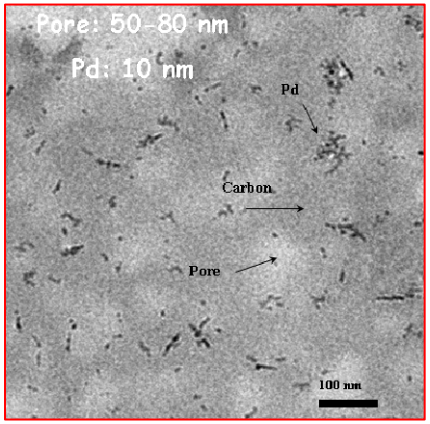
$Na_3AlD_{6-x}F_x$

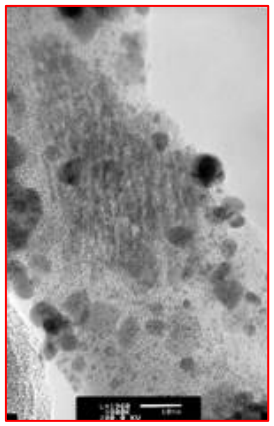
IFE patent appl. (2006); Brinks, Fossdal, Hauback (in press)

✓Nanoporous structures → Metal-doped carbons:

- Synthesis of novel carbogenic foam with high surface spin concentration
- Synthesis of Pd/C foam nanocomposites to exploit the "spillover effect" → H_2 uptake: > 2 wt % at 298 K
- Synthesis of Pd-alloy/C foam nanocomposites → Enhanced H_2 uptake (> 4 wt%) at 298 K (verified also by JRC and SwRI)







NCSR "Demokritos", Athens - Greece

Carbon, **45** (2007) 852-857

✓Metal-doped carbons (simulation):

- theoretical studies of Li-intercalated nanoscrolls → GCMC calculations predict H_2 uptake ~ 4 wt % at 293 K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Special Reports

Technology

Roll up for better hydrogen fuel storage

13:45 25 June 2007
NewScientist.com news service
Duncan Graham-Rowe

The thorny problem of how to store hydrogen fuel safely for future vehicles and portable gadgets could be solved by simply storing it in nanoscopic scrolls of carbon.

Scientists in Greece say they have found a way to make so-called "carbon nanoscrolls" store more hydrogen than any other material.

By adding impurities to rolled sheets of carbon in detailed computer simulations, they found they could control how tightly the scrolls wind up and, hence, how much hydrogen they adsorb.

This result is very promising because it provides a potential solution to one of the major problems of hydrogen storage for mobile applications, says George Froudakis at the University of Crete, who led the work.

Tools

digg reddit

Related Articles

'Nanoporous' material gobbles
07 November 2006
New type of hydrogen fuel cell
13 September 2006
Fuel cell squeezes more from
09 April 2005

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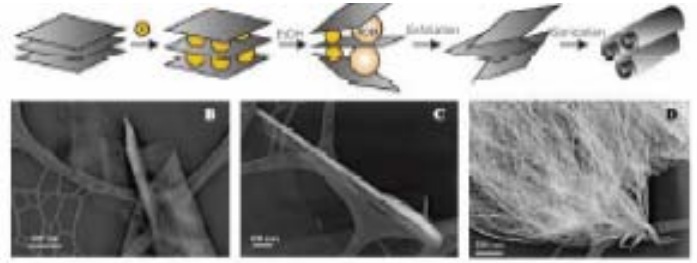
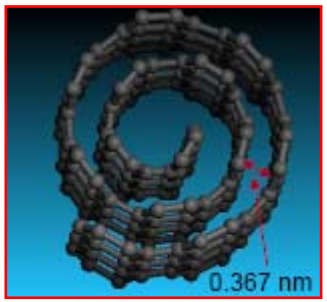
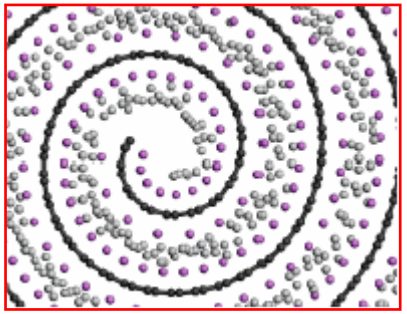


Viculis et al., Science, 299 (2003), 1361



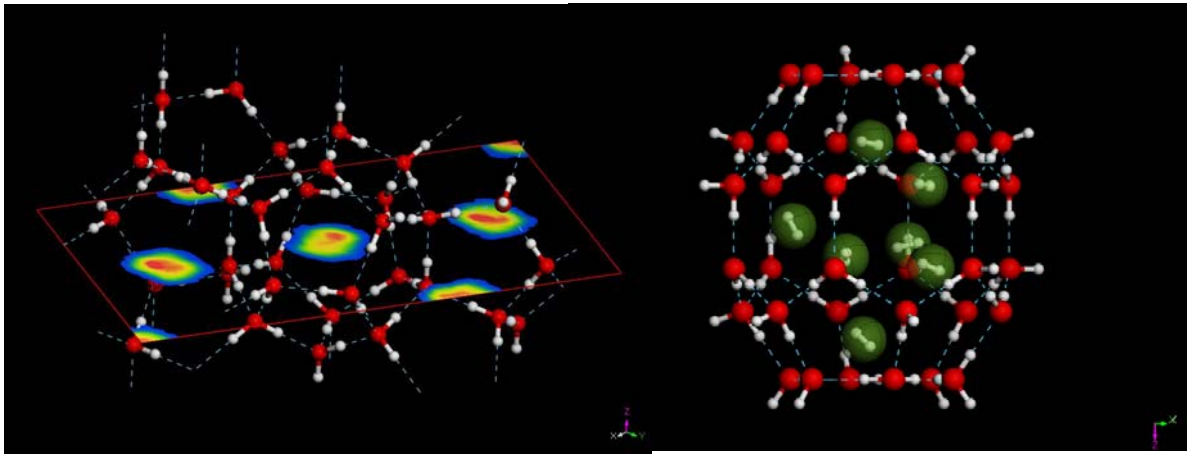


Dept. of Chemistry, Univ. of Crete, Heraklion – Greece
NCSR "Demokritos", Athens - Greece

Nano Letters, **7** (2007) 1893-1897

✓Hydrogen clathrates:

- Simulations suggest that H_2-THF sII clathrates cannot store more than 1.1 wt% H_2 at pressures up to 1200 bar and close-to-ambient temperatures
- For the first time, H_2 hydrates with the sH structure have been synthesized (TUD). Estimated H_2 storage capacity → 1.4%
- Simulations (NCSRD), suggest that if a promoter can stabilize the "medium" cavity, up to 7 H_2 molecules can be stored in the "large" cavity → H_2 content up to 4 wt%

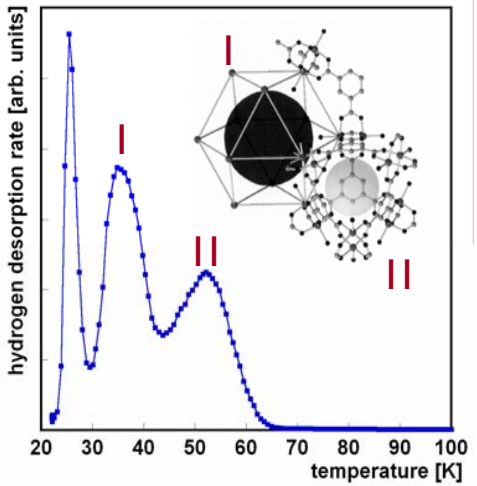


J. Phys. Chem. B, 112 (2008), 1888 -1889

✓MOFs:

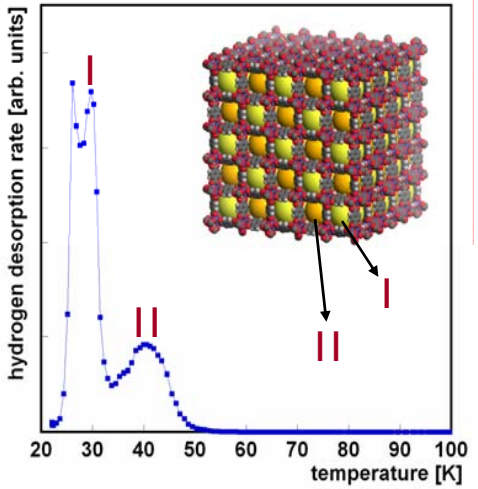
- Low temperature (from 20 K) thermal desorption spectroscopy measurements revealed adsorption sites → strongest adsorption in small pores

Cu-BTC



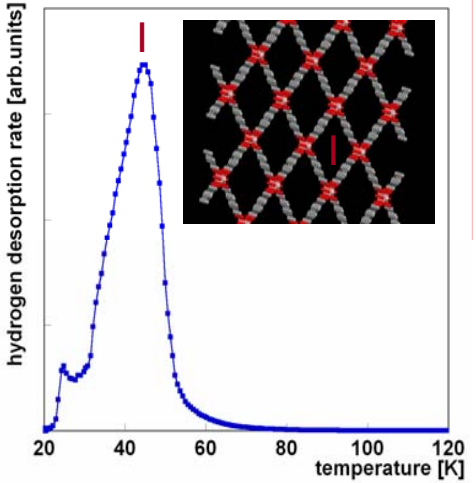
Picture from Krawiec et al. *Adv. Eng. Mater*. **8** (2006) 293

MOF-5



Picture kindly provided by J. Rowsell

MIL-53



Angew. Chem. Int. Ed., **47 (**2008), 2138-2142

✓Tanks:

- Large scale production of Mg based hydrides and development of storage tanks (2 kg of material available)
- 10 kg MgH_2 tank under development

Equal-channel angular processing (ECAP)

Industrial scale Milling

2 kg MgH_2 tank, ≈ 5 kWh

(120 gr - 1344 NL H_2)

External volume : 3 l
Weight ≈ 12 kg
Max Pressure: 1.5 MPa

CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

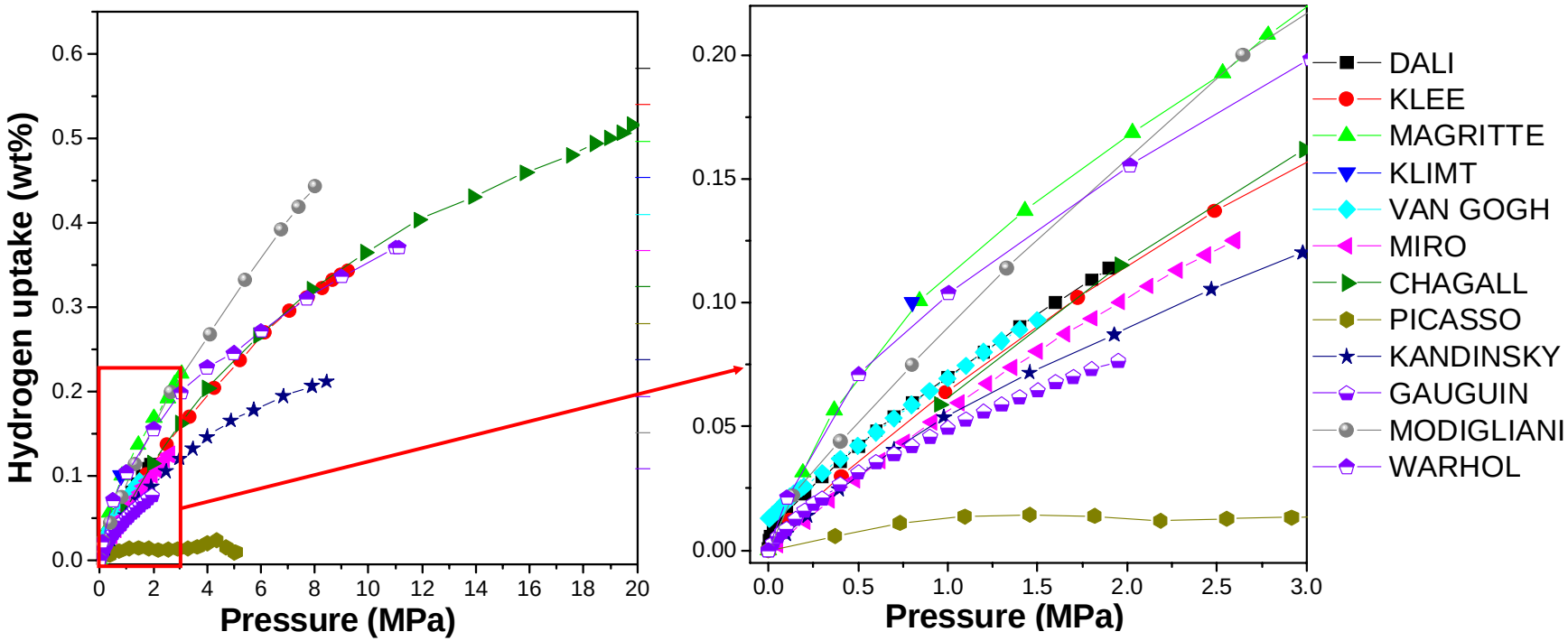
✓Tanks:

- Development of a lab-scale (500 ml) complex hydride ($NaAlH_4$) tank → testing in progress

- Large scale (0.4 kg H_2) $NaAlH_4$ tank under development

✓Organisation of the first Round Robin Tests in Europe:

- Physisorption @ 77K (commercial Carbon Molecular Sieve) - Completed
- Complex hydride (already started) & Mg-based materials (starting soon)
- In collaboration with SwRI/DoE and external (EU & non EU) organisations
- Analysis in progress



EUROPEAN COMMISSION JRC ie Institute for Energy

NESSHY Training & Dissemination activities

- **www.nesshy.net**
- NESSHY Newsletter
- IPHE recognition (*September 2006*)
- Training and dissemination events with wide multi-national participation have been supported up to now by NESSHY
  - Hydrogen Summer School, University of Iceland - Reykjavik (*2006, 2008*)
  - One day Magnesium Titanium Hydride workshop, Vrije Universiteit - Amsterdam (*August 2006*)
- Interaction with other hydrogen related projects funded by EC (HYTRAIN, COSY, HYDROGEN RTNs, SURMOF, MOFCAT, HYCONES, NANOHY)
- More than 190 papers in journals/conferences in the first 2 years of the project
- 8 patent applications

Enhancing Cooperation

Collaboration with other FP6 & FP7 projects

	Project	Coordinator	Topic
Energy Priority	**STORHY** **www.storhy.net** 2004-2008	Magna Steyr *Austria*	Next generation H_2 storage technologies (compressed gas, cryogenic liquid and solid materials*) with a focus on automotive applications * Na-alanate, mixed alanates, alane
	NANOHY **www.nanohy.eu** 2008-2011	Forschungszentrum Karlsruhe *Germany*	Nanocomposites consisting of hydride particle sizes in the lower nm range protected by a nanocarbon template or by self-assembled polymer layers in order to prevent agglomeration
NMP Priority	**HYCONES** **www.hycones.eu** 2006-2009	NCSR Demokritos *Greece*	Hydrogen storage in carbon cones
	SURMOF **www.rhur-uni-bochum.de/pc1/SURMOF** 2006-2009	Rhur University *Austria*	Anchoring of MOFs to surfaces
	MOFCAT **www.sintef.no** 2006-2011	SINTEF *Norway*	Functional MOFs as heterogeneous catalysts and adsorbents
Marie Curie Research Training Networks (RTN)	**HYTRAIN** **www.hytrain.net** 2005-2008	University of Salford *UK*	Mg-base hydrides, complex hydrides (e.g. alanates, borohydrides), novel light hydrides (e.g. Li nitrides, amides)
	COSY **www.cosy-net.eu** 2006-2009	GKSS *Germany*	Fundamental understanding of the sorption kinetics in reactive hydride composites
	HYDROGEN **www.theorchem.leidenuniv.nl** 2006-2009	Leiden University *The Netherlands*	Hydrogen storage in alanates, borohydrides and a new class of materials to store it in form of ammonia

Enhancing Cooperation

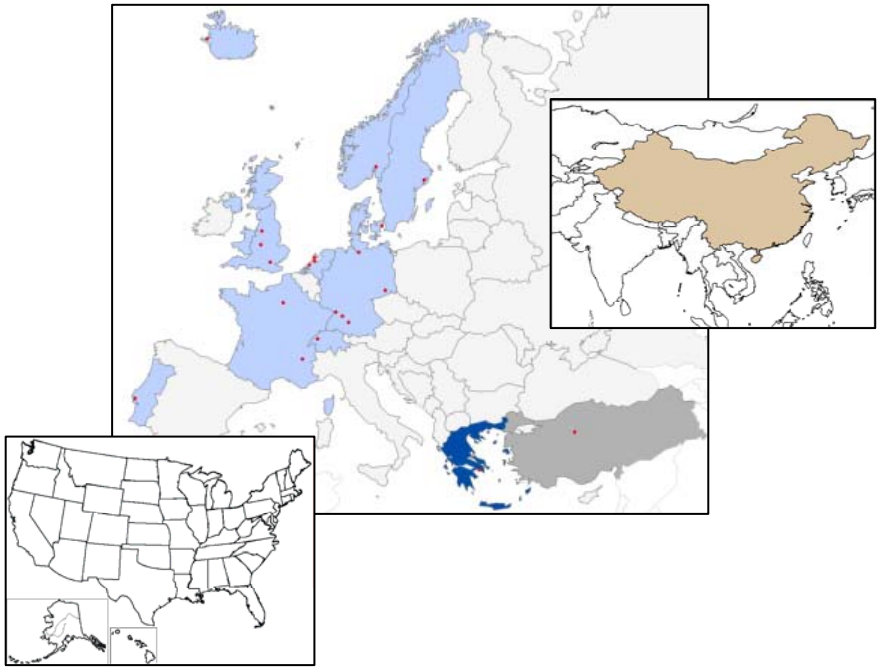
International Collaborations

➔ **IPHE** label (September 2006)

➔ Participation of **SwRI**, the American institute officially appointed by DoE for standardisation in H_2 solid storage measurements

➔**HySIC**: "Enhancing International Cooperation in running FP6 Hydrogen Solid Storage Activities" Specific Support Action linked to NESSHy (2007-2008)

- 8 partners from EU, Russian Federation, P. R. China and Lithuania
- Key Objectives:
  - *Performance of studies enhancing international cooperation (sample preparation and characterisation, benchmarking, round-robin testing, testing protocol standardization)*
  - *Joint dissemination actions (workshops and integration activities)*



- **Duration: 1.1.2007 – 31.12.2008 (2-years)**
- **Official project Start: January 1, 2007**
- **Budget: 310,850 €**
- **EU Contribution: 300,000 €**

Website: http://milos.ipta.demokritos.gr/hysic

HySIC Consortium

Organization	Country
National Centre for Scientific Research "Demokritos" (NCSRD)	Greece
Stockholms Universitet (SU)	Sweden
University of Salford (USAL)	UK
Institutt for Energiteknikk (IFE)	Norway
Lithuania Energy Institute (LEI)	Lithuania
Institute of New Energy Material Chemistry of Nankai University (INEMC)	P.R. China
Institute of Solid State Physics of the Russian Academy of Sciences (ISSP-RAS)	Russian Federation
General Research Institute For Non-ferrous Metals (GRINM)	P.R. China

✓2 Supporting activities:

➔ **Performance of Studies Enhancing International Cooperation:**

- Sample preparation and exchange among *HySIC* partners for round-robin testing that involves structural, thermodynamic and kinetic characterization using various methods including micro-gravimetric techniques, electrochemical measurements and neutron scattering.
- Evaluation of results with a view to sample and testing protocol standardization.

➔ **Joint Dissemination Actions and Integration of HySIC/NESSHY Activities**

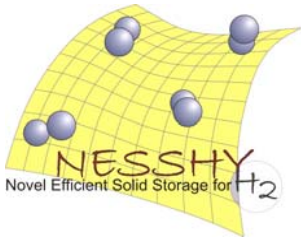
The HySIC SSA Experience

- Staff exchanges (GRINM/USAL/IFE; LEI/SU/ISSP-RAS) for training and R&D
- Sample synthesis and exchanges (all partners)
- Participation to NESSHY Round Robin Tests
- Potential joint publications
- Joint experimental campaigns : (USAL/Nankai: Neutron Scattering on Mg-nanowires)

- Joint HySIC-NESSHY dissemination actions in China:

  - ***Workshop Sept., 08***:

    - Wide participation of Chinese groups working on H-storage
    - Visits to GRINM, LN-Power Sources Co.
    - Opportunities for further collaboration



Benefits of being an "IPHE-labeled" project

- **The *label* as such offers a certain potential but IS NOT sufficient to establish long lasting collaborations.**

- **More concrete actions need to be taken.**

Our experience suggests that focused Specific Support Actions, *even* with small budget like *HySIC*, may promote efficiently the IPHE aims at International level.

NESSHY
Novel Efficient Solid Storage for H_2

The NESSHY Team