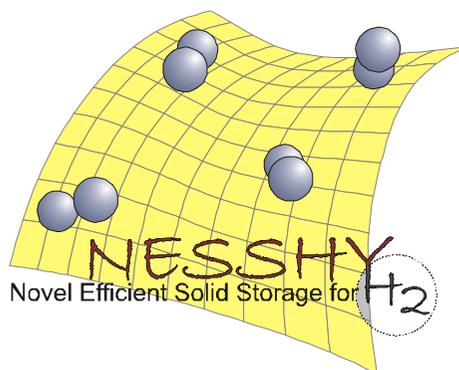




# NESSHY

## “Novel Efficient Solid Storage for Hydrogen”

Integrated Project SES6-CT-2006-518271



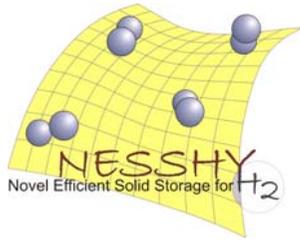
**Theodore Steriotis**

Institute of Physical Chemistry

National Center for Scientific Research «Demokritos»

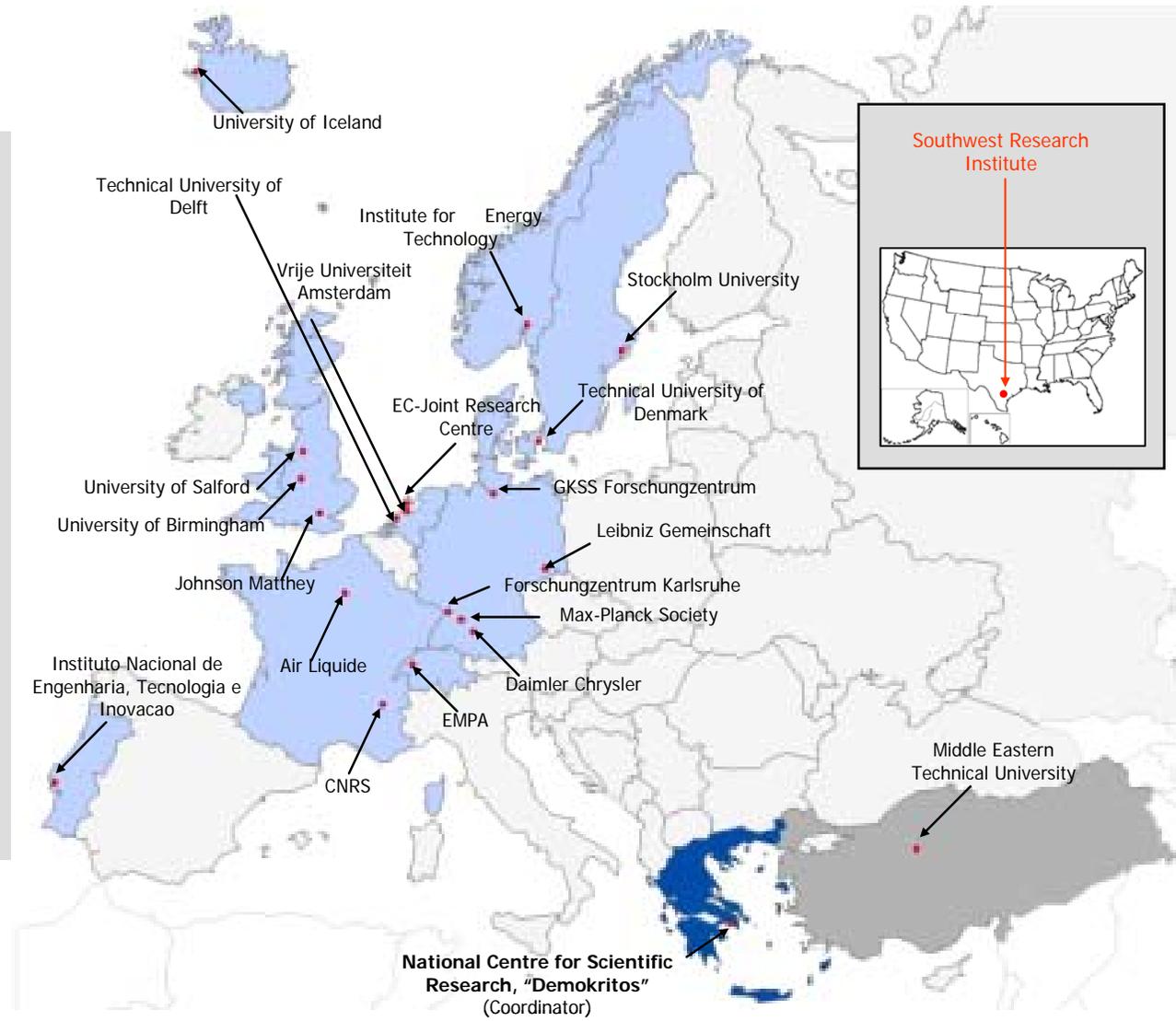
Athens - Greece





# 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)**

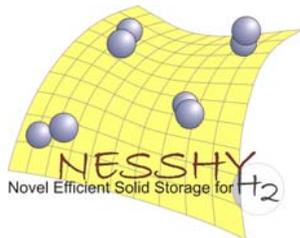




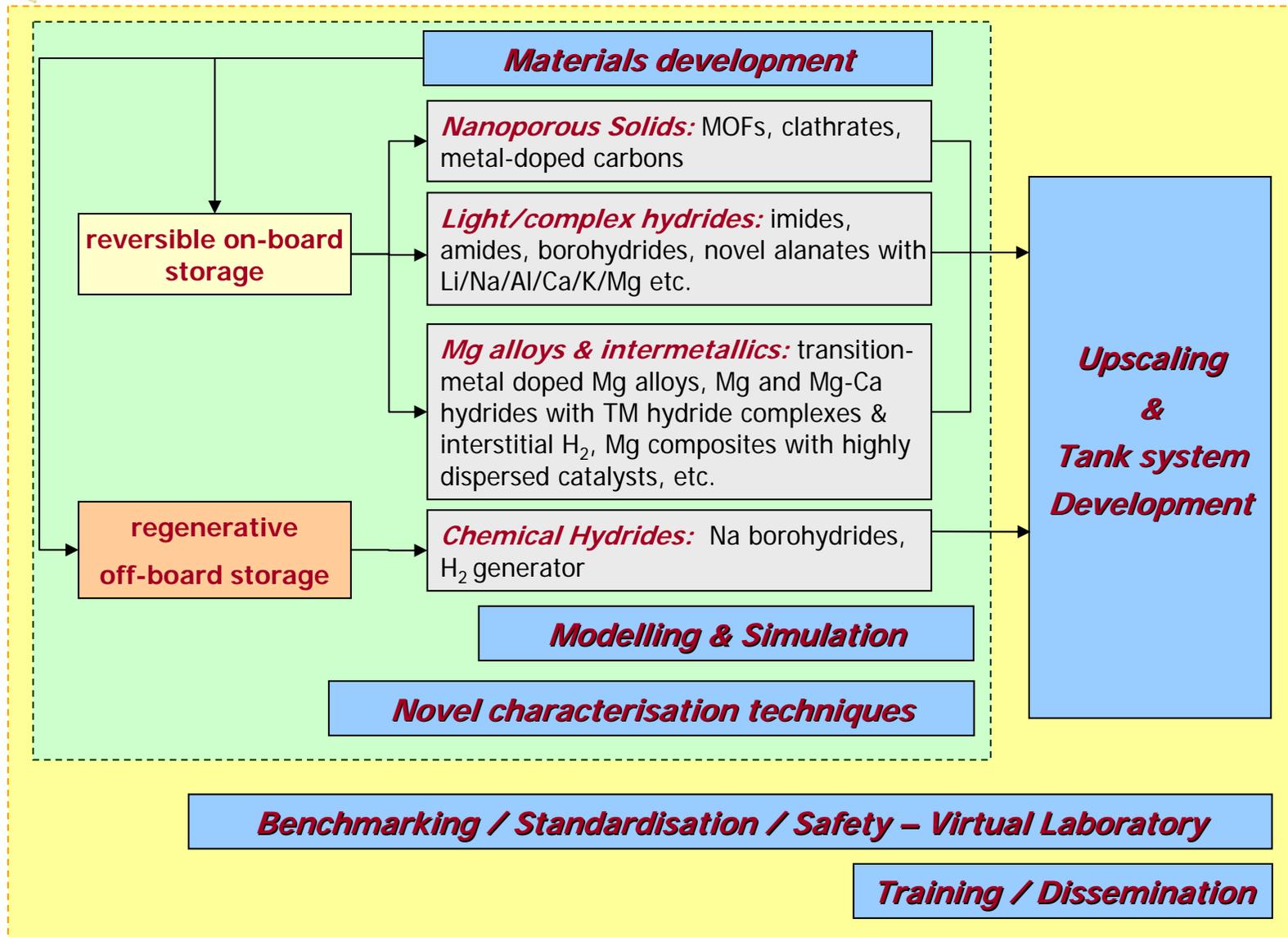
## *NESSHY vision*

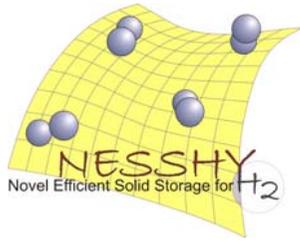
**NESSHY aims at advancing the current state of hydrogen storage in solid materials, with respect to**

- ✓ **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**

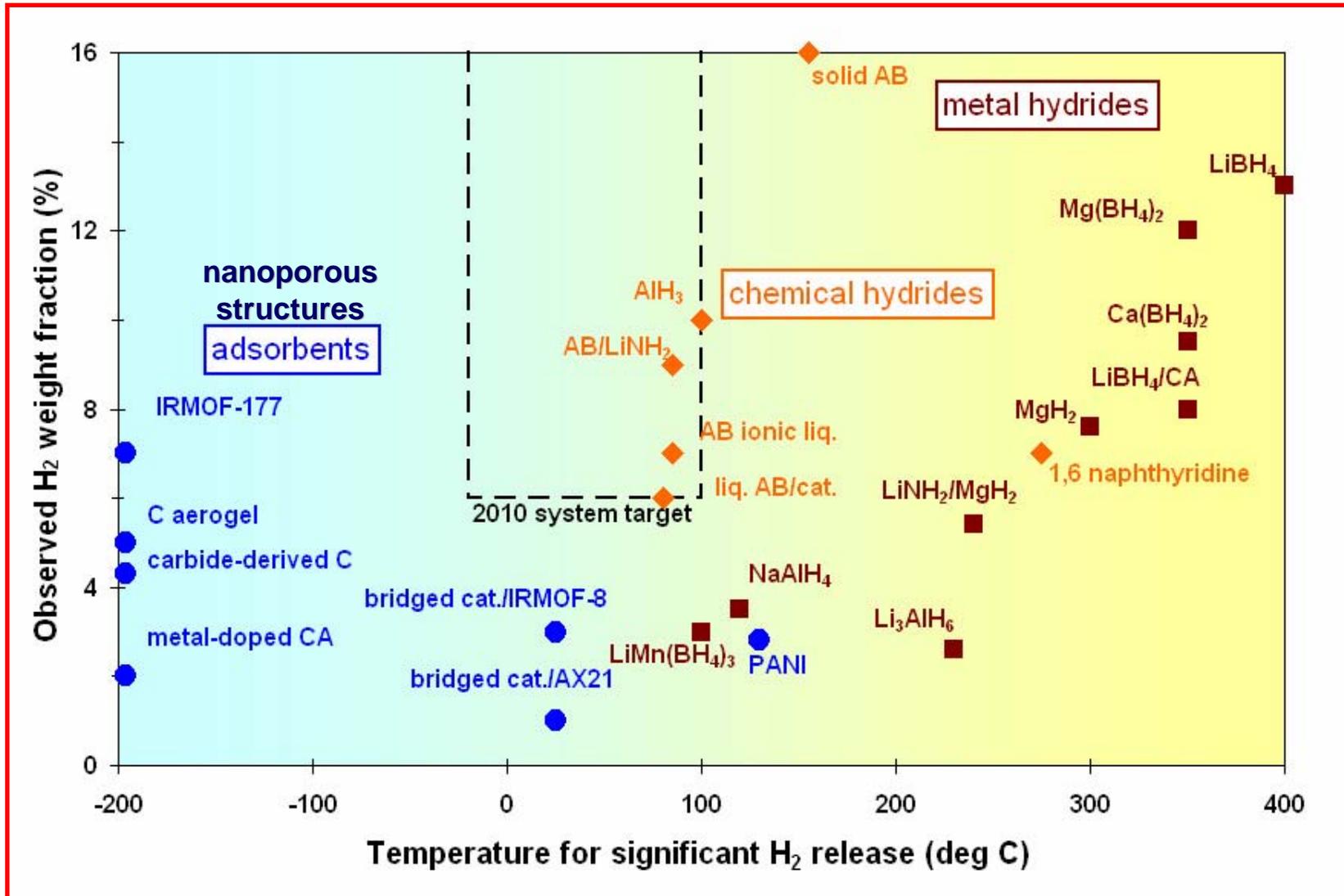


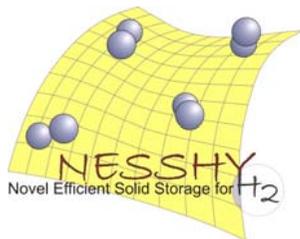
# NESSHY workplan





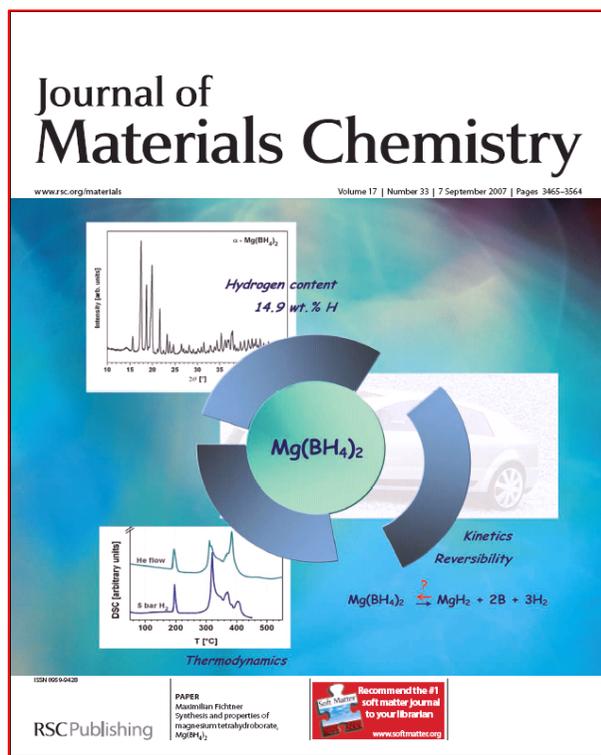
*Materials State of the art*



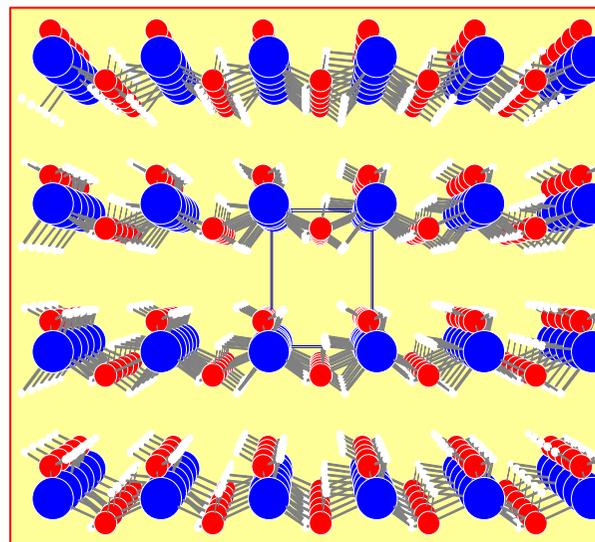


## NESSHY 24 Month Highlights - Materials

- ✓ Novel synthesis of magnesium tetrahydroborate,  $\text{Mg}(\text{BH}_4)_2 \rightarrow$  potential for  $\text{H}_2$  storage (14.9 mass % H & suitable thermodynamic properties)

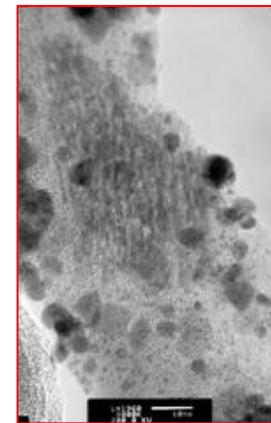
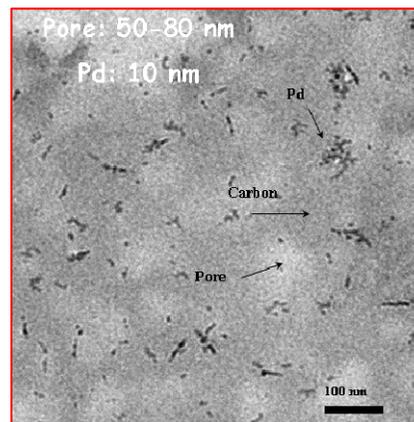
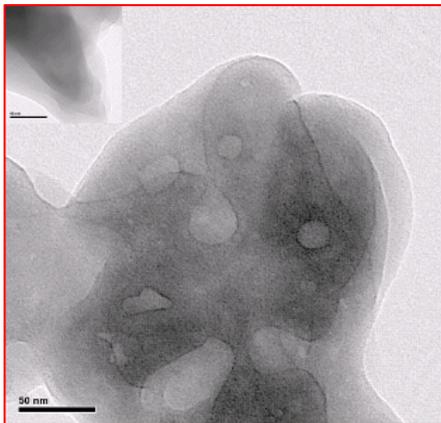


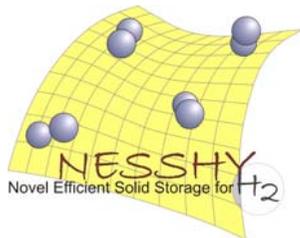
*J. Mater. Chem.*, **17** (2007) 3496–3503



### ✓ **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<sub>2</sub> uptake: >2 wt % at 298 K
- Synthesis of Pd-alloy/C foam nanocomposites → Enhanced H<sub>2</sub> uptake at 298 K (verified also by JRC and SwRI)

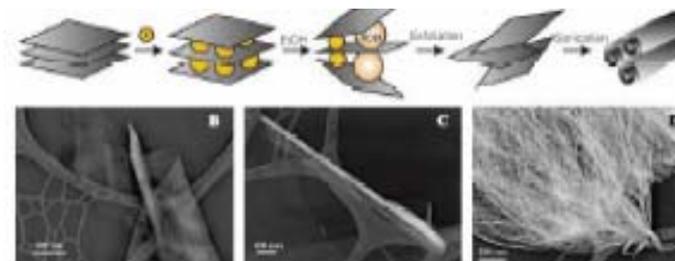




## NESSHY 24 Month Highlights - Materials

### ✓ Metal-doped carbons (simulation):

- theoretical studies of Li-intercalated nanoscrolls → GCMC calculations predict H<sub>2</sub> uptake ~ 4 wt % at 293 K



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

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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.

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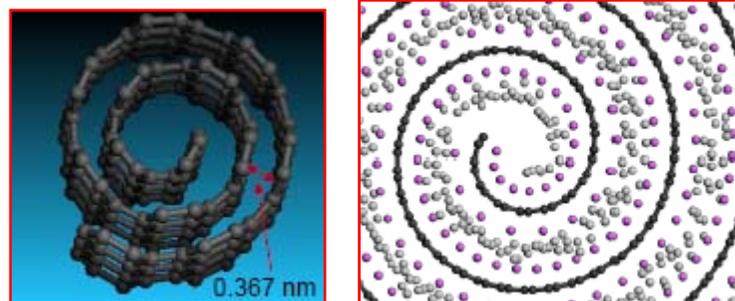
**Related Articles**

[Nanoporous material gobbles](#) 07 November 2006

[New type of hydrogen fuel cell](#) 13 September 2006

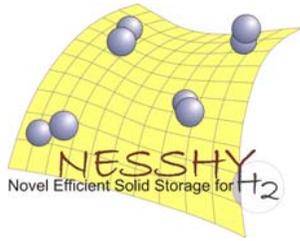
[Fuel cell squeezes more from p](#) 09 April 2005

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

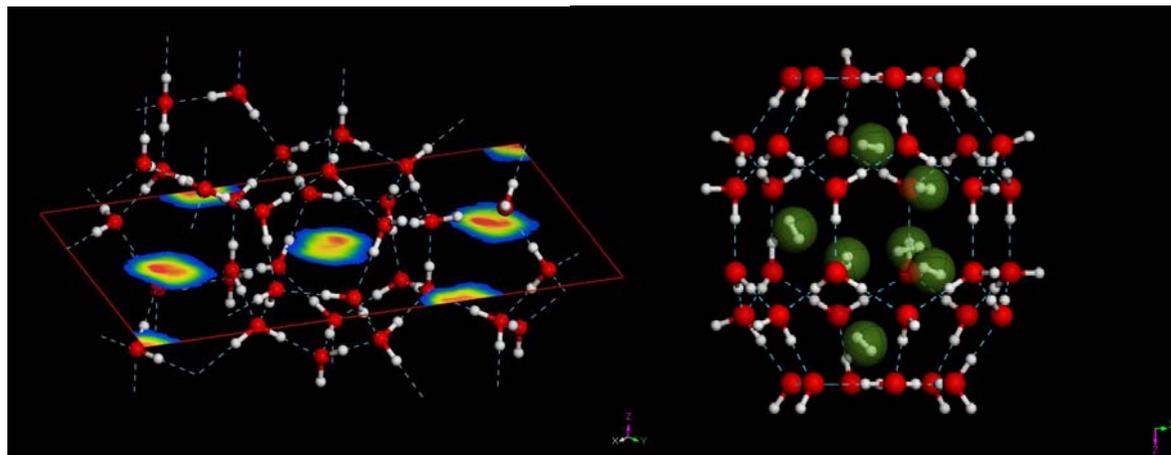
*Nano Letters*, 7 (2007) 1893-1897



## NESSHY 24 Month Highlights - Materials

### ✓ Hydrogen clathrates:

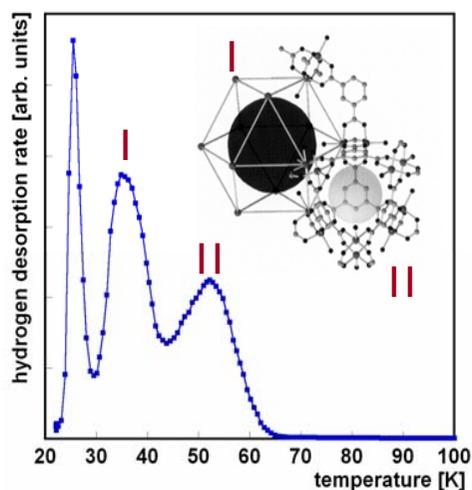
- Simulations suggest that H<sub>2</sub>-THF sII clathrates cannot store more than 1.1 wt% H<sub>2</sub> at pressures up to 1200 bar and close-to-ambient temperatures
- For the first time, H<sub>2</sub> hydrates with the sH structure have been synthesized (TUD). Estimated H<sub>2</sub> storage capacity → 1.4%
- Simulations (NCSR D), suggest that if a promoter can stabilize the “medium” cavity, up to 7 H<sub>2</sub> molecules can be stored in the “large” cavity → H<sub>2</sub> content up to 4 wt%



## ✓ MOFs:

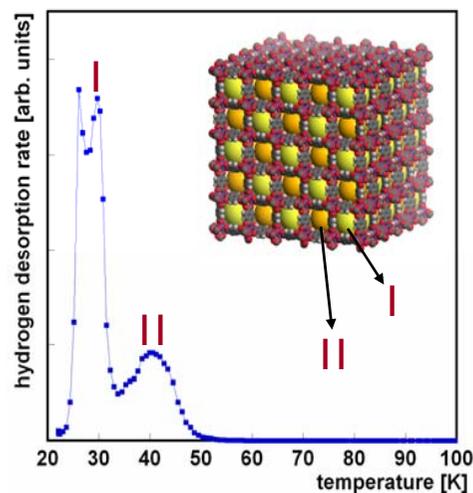
- Low temperature (from 20 K) thermal desorption spectroscopy measurements revealed adsorption sites → strongest adsorption in small pores

### Cu-BTC



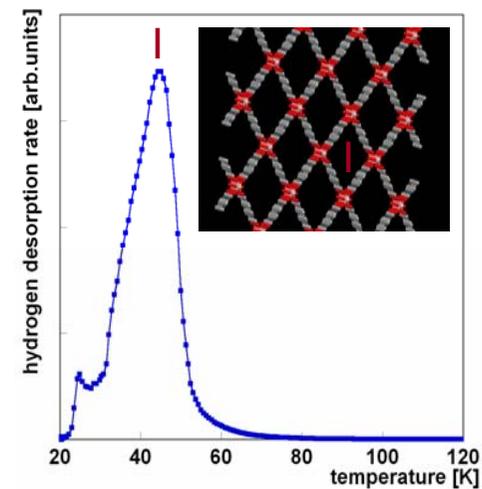
Picture from Krawiec et al. *Adv. Eng. Mater.* **8** (2006) 293

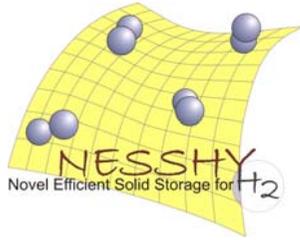
### MOF-5



Picture kindly provided by J. Rowsell

### MIL-53





## *NESSHY 24 Month Highlights - Upscaling & Storage systems*

### ✓ Tanks:

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



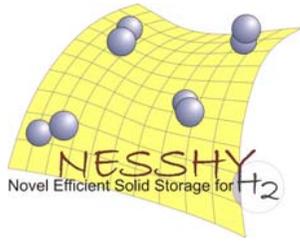
Equal-channel angular processing (ECAP)



Industrial scale Milling



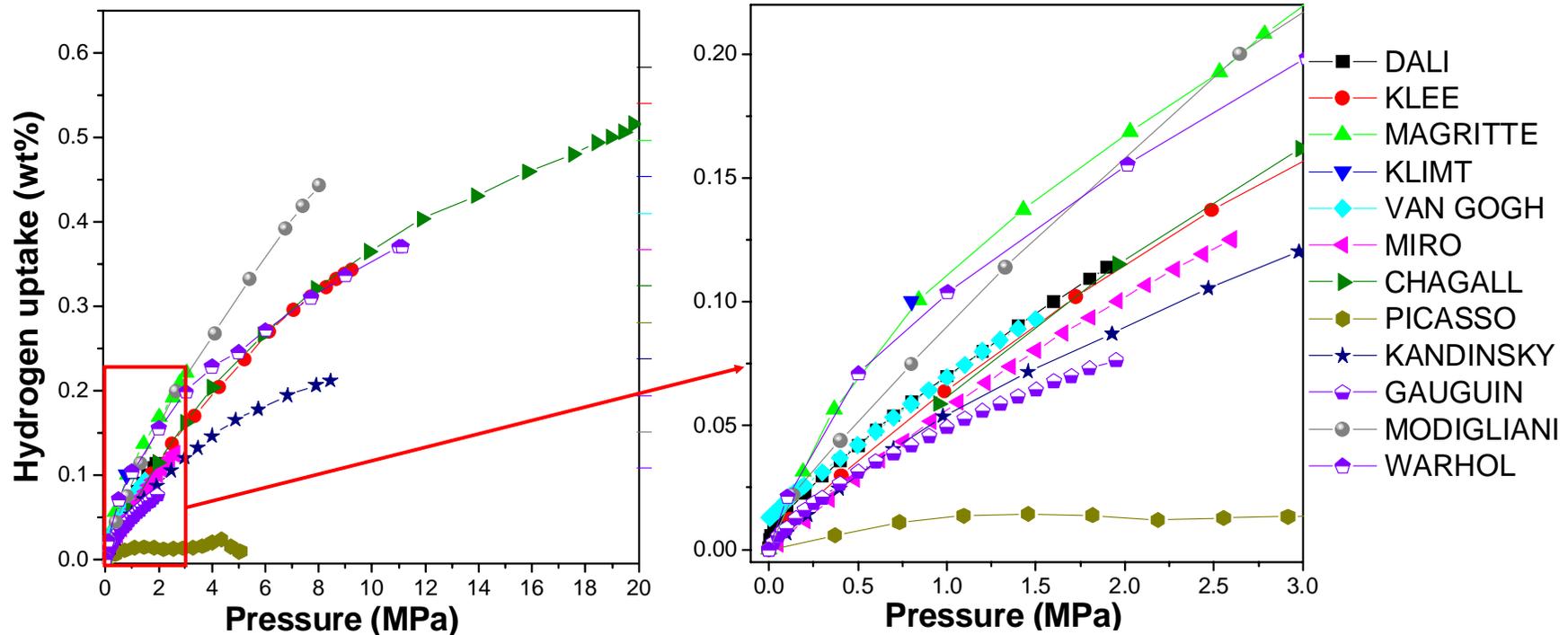
Helmet torch powered by Mg tank

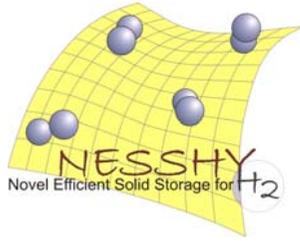


## NESSHY 24 Month Highlights - RRTs

### ✓ Organisation of the first Round Robin Test in Europe:

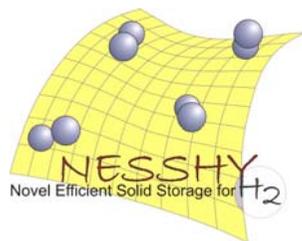
- Physisorption @ 77K (commercial Carbon Molecular Sieve) - Completed
- Complex hydride (already started) & Mg-based materials (starting soon)
- In collaboration with SwRI/DoE and external (EU & non EU) organisations
  - Analysis in progress





## *NESSHY Training & Dissemination activities*

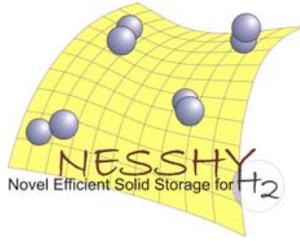
- [www.nesshy.net](http://www.nesshy.net)
- IPHE recognition (September 2006)
- Interaction with other hydrogen related projects (HYTRAIN, COSY, HYDROGEN RTNs, SURMOF, MOFCAT, HYCONES)
- Two training and dissemination events with wide multi-national participation have been supported up to now by NESSHY
  - Hydrogen Summer School, University of Iceland - Reykjavik (June 2006)
  - One day Magnesium Titanium Hydride workshop, Vrije Universiteit - Amsterdam (August 2006)
- NESSHY Newsletter
- Establishment of collaboration with Chinese and Russian organisations → Specific Support Action **HYSIC**
- More than 50 papers in journals/conferences in the 1<sup>st</sup> year of the project



# Enhancing Cooperation

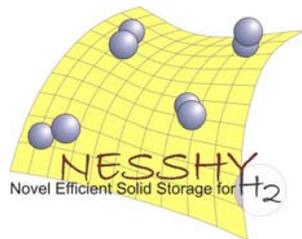
## *Collaboration with other FP6 projects*

	<b>Project Acronym</b>	<b>Coordinator</b>	<b>Topic</b>
<b>Energy Priority</b>	<b>STORHY</b> <a href="http://www.storhy.net">www.storhy.net</a> 2004 – 2008	Magna Steyr <i>Austria</i>	Next generation H <sub>2</sub> storage technologies (compressed gas, cryogenic liquid and solid materials*) with a focus on automotive applications  *Na-alanate, mixed alanates, alane
<b>NMP Priority</b>	<b>HYCONES</b> <a href="http://www.hycones.eu">www.hycones.eu</a> 2006 – 2009	NCSR Demokritos <i>Greece</i>	Hydrogen storage in Carbon cones
	<b>SURMOF</b> <a href="http://www.ruhr-uni-bochum.de/pc1/SURMOF">www.ruhr-uni-bochum.de/pc1/SURMOF</a> 2006 – 2009	Rhur University <i>Germany</i>	Anchoring of MOFs to surfaces
	<b>MOFCAT</b> <a href="http://www.sintef.no">www.sintef.no</a> 2006 - 2011	SINTEF <i>Norway</i>	Functional MOFs as heterogeneous catalysts and adsorbents
<b>Marie Curie Research Training Networks (RTN)</b>	<b>HYTRAIN</b> <a href="http://www.hytrain.net">www.hytrain.net</a> 2005 - 2008	University of Salford <i>UK</i>	Mg-based hydrides, complex hydrides (e.g. alanates, borohydrides), novel light hydrides (e.g. Li nitrides, amides)
	<b>COSY</b> <a href="http://www.cosy-net.eu">www.cosy-net.eu</a> 2006 - 2009	GKSS <i>Germany</i>	Fundamental understanding of the sorption kinetics in reactive hydride composites
	<b>HYDROGEN</b> <a href="http://www.theorchem.leidenuniv.nl">www.theorchem.leidenuniv.nl</a> 2006 - 2009	Leiden University <i>The Netherlands</i>	Hydrogen storage in alanates, borohydrides, and 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<sub>2</sub> solid storage measurements
- **HySIC**: “Enhancing International Cooperation in running FP6 Hydrogen Solid Storage Activities” Special Scientific Action linked to NESSH<sub>y</sub> (2007-2008)
  - 8 partners from EU, Russian Federation, P. R. China and Lithuania
  - Objectives:
    - *Performance of studies enhancing international cooperation (benchmarking, round-robin testing, testing protocol standardization)*
    - *Joint dissemination actions (workshops and integration activities)*



more information at

[www.nesshy.net](http://www.nesshy.net)

The screenshot shows the NESSHY website in a Microsoft Internet Explorer browser window. The browser's address bar displays <http://www.nesshy.net/>. The website header includes the NESSHY logo and the text "Novel Efficient Solid Storage for H2". A navigation menu contains links for Home, Partners, Publications, Events, Job Opportunities, Links, and Contact. The main content area is titled "Home Page" and contains the following text:

Integrated Project NESSHY, partly funded by the European Commission in the context of the 6<sup>th</sup> Framework Programme for Research (6FP), is coordinated by the Environmental Research Laboratory of the National Research Center "Demokritos" (EL) and aspires to comprise the major European initiative in the field of Hydrogen Storage in Solids. The project started officially on January 1, 2006, with a contractual duration of five years.

**Objectives**

NESSHY aims at developing novel materials, storage methods and fabrication processes that provide the energy density and the charge/discharge, storage/restitution rates necessary for mobile applications with spin-offs in stationary systems. The final aim of the project is to identify the most promising solid storage solutions for such applications. The envisaged objectives cover **porous storage systems**, **regenerative hydrogen stores** (such as the borohydrides) and solid hydrides having reversible hydrogen storage and improved gravimetric storage performance. Initially, two categories of reversible stores will be investigated – **light/complex hydrides**, such as **alanates** and **imides**, and **intermetallic** systems involving magnesium, although further categories may be included later. In all cases, the performance of different systems will be compared by a standards laboratory (working in collaboration with the US DoE standardisation activity). Further, efforts will be made to understand the mechanisms involved by innovative modelling activities. When promising new materials are identified, industrial and R&D collaborators will be brought in to upscale the material production, develop appropriate demonstration storage tanks and test out the prototype stores in practical conditions.

**Approach and innovation**

NESSHY addresses key issues related to hydrogen storage in solid materials such as new...

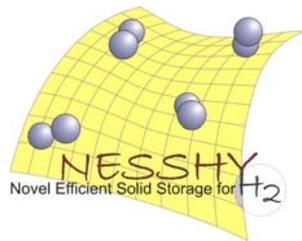
**Private Area Login**

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Password:

**Latest Announcements**

- 2<sup>nd</sup> Annual NESSHY Governing Board Meeting: December 12-14, 2007 – Istanbul (hosted by METU)
- 1<sup>st</sup> NESSHY electronic Newsletter (February 2007)
- Job Opportunities

FP6 Integrated Project NESSHY  
Contract no.: SES6-510271 (2006-2011)  
Coordinator: Dr. A. Stubos – NESR Demokritos, Athens-Greece  
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The NESSHY Team