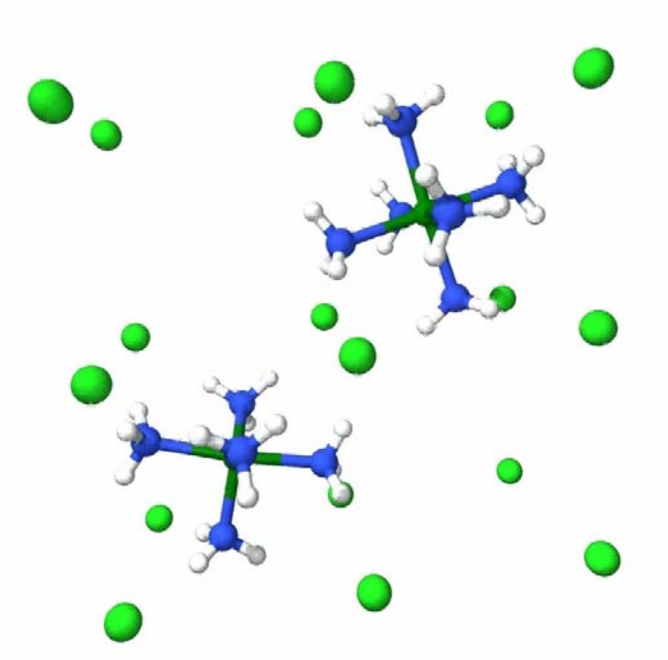
Novel Indirect Hydrogen Storage Materials



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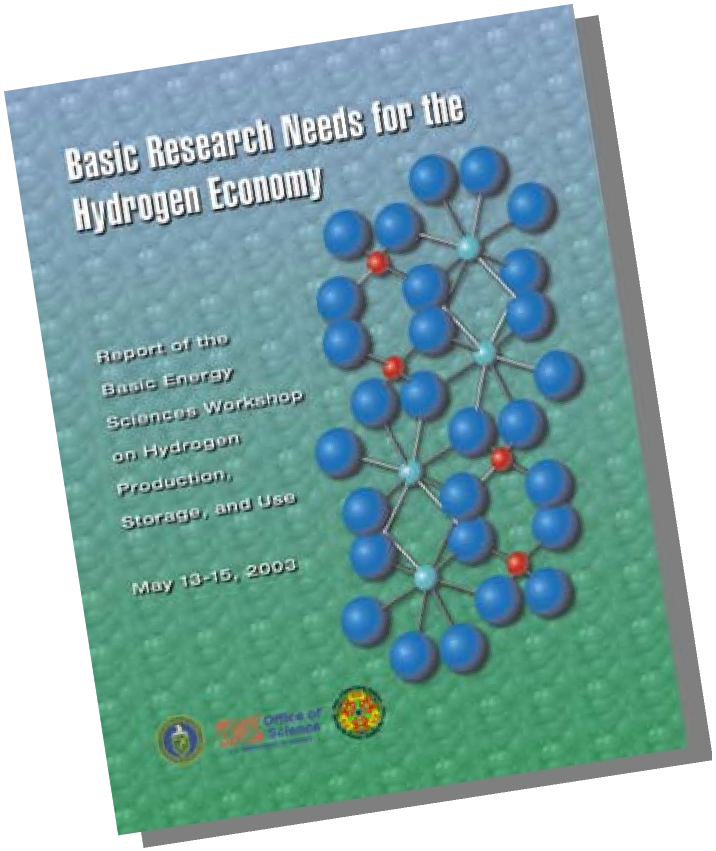
Center for Sustainable and Green Chemistry

www.csg.dtu.dk

Basic Research Needs for the Hydrogen Economy



March 23, 2004
APS March Meeting
Montreal, Canada

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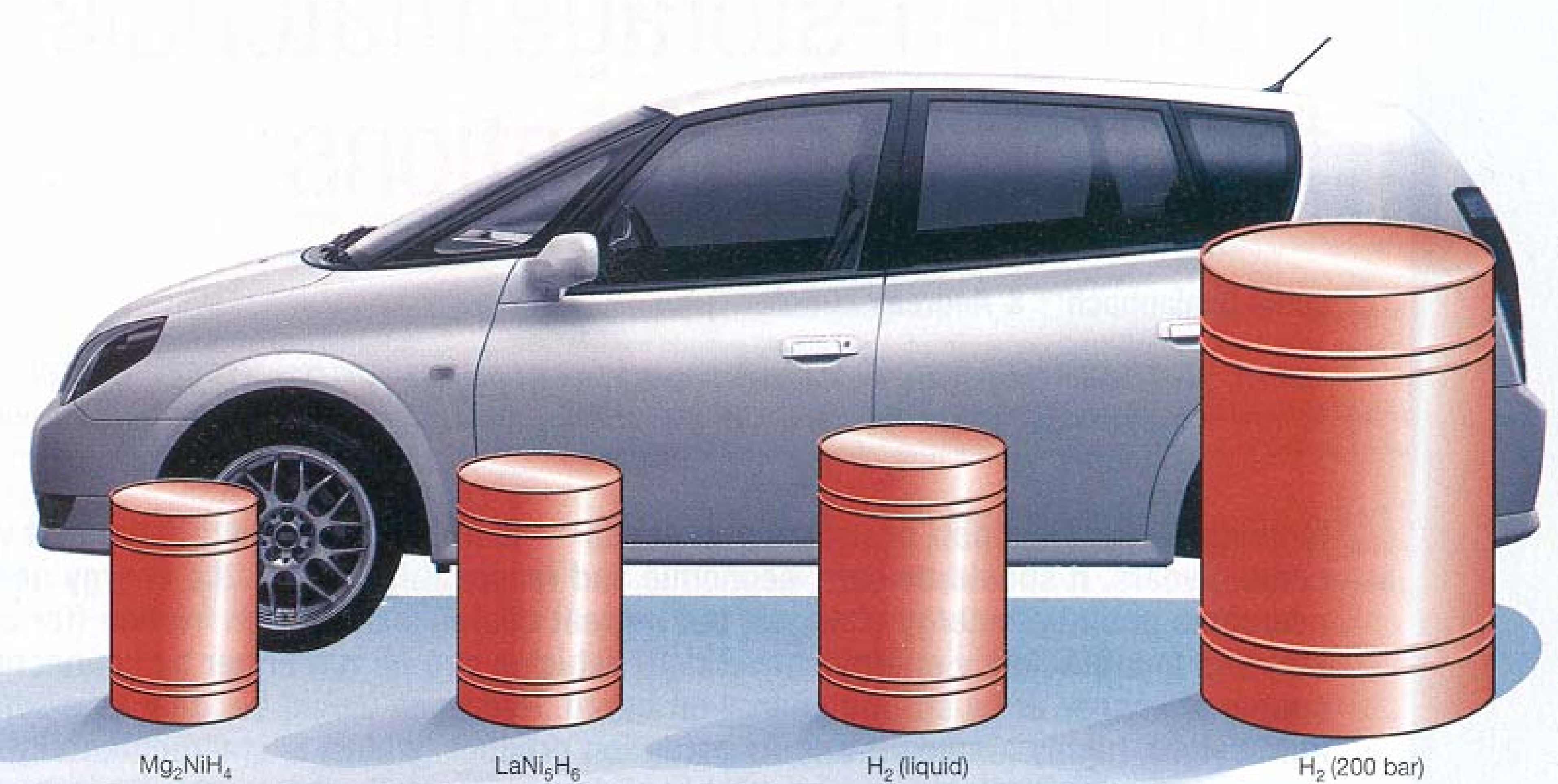
Hydrogen Storage for Vehicles



3.59 wt% **1.37 wt%**

Schlapbach & Züttel, *Nature*

Direct Hydrogen Storage

- Liquefied H_2
  - Boil-off, cost of liquefying, safety
- High pressure H_2
  - Cost of compression, safety, volumetric density
- Metal hydrides, e.g. MgH_2
  - Low bulk density, kinetics
- Complex hydrides, e.g. $NaAlH_4$, $LiAlH_4$
  - kinetics/catalyst, synthesis, reversibility
- Chemical hydrides, e.g. borane-ammonia adducts
  - Expensive materials, reversibility, complex system
- Physisorption in porous materials
  - Material developments, synthesis, gravimetric and volumetric density

Indirect Hydrogen Storage

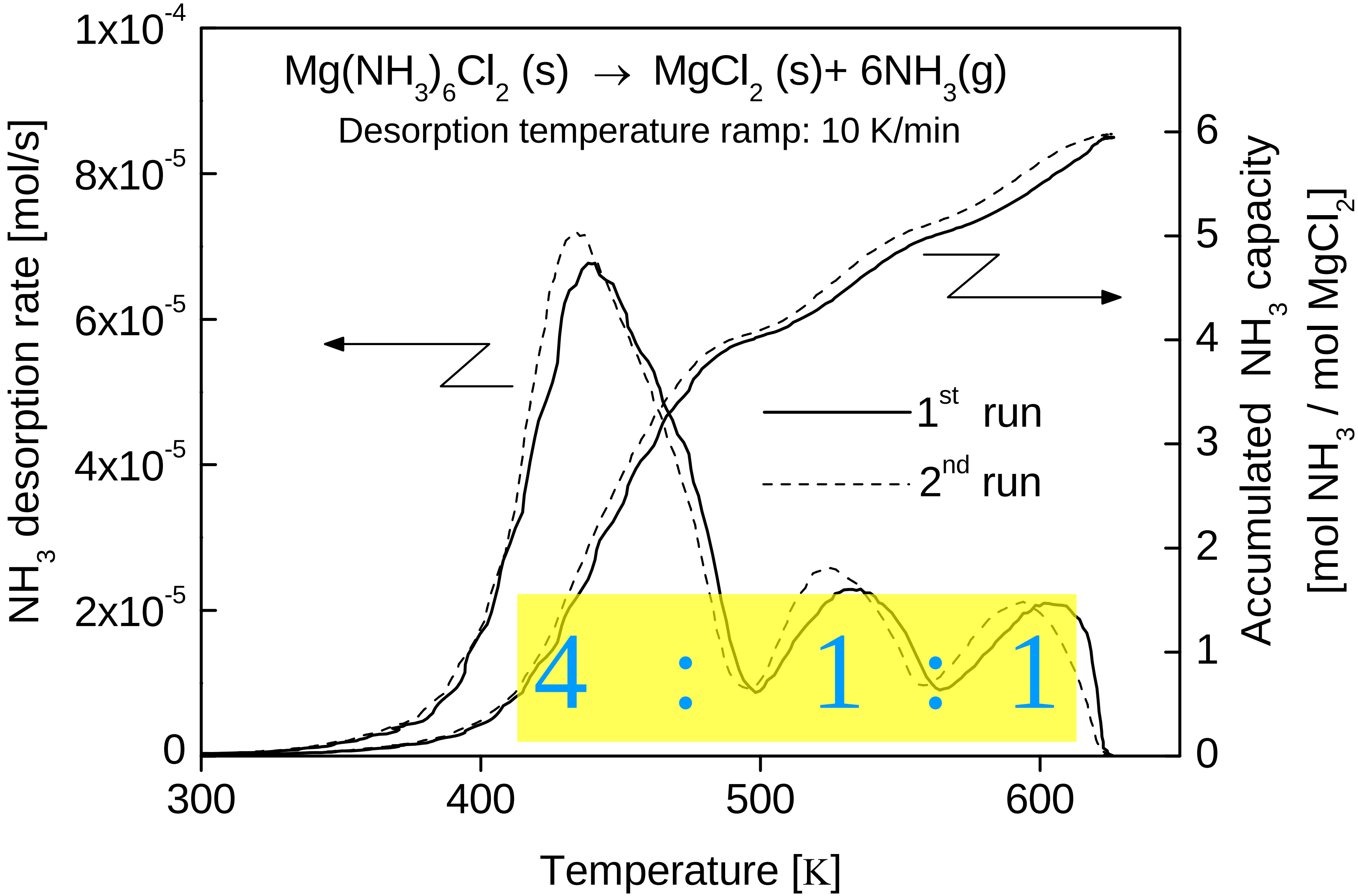
- Methane
  - reforming, reformate clean-up, volumetric density
- Methanol
  - reforming, reformate clean-up, safety
- Ethanol
  - reforming, reformate clean-up, cost
- Ammonia
  - reforming, safety

Ammonia as Hydrogen Carrier

- Dense liquid; ~ 18wt% of hydrogen
- Optimized catalyst exist
- Relatively easy to reform to H_2

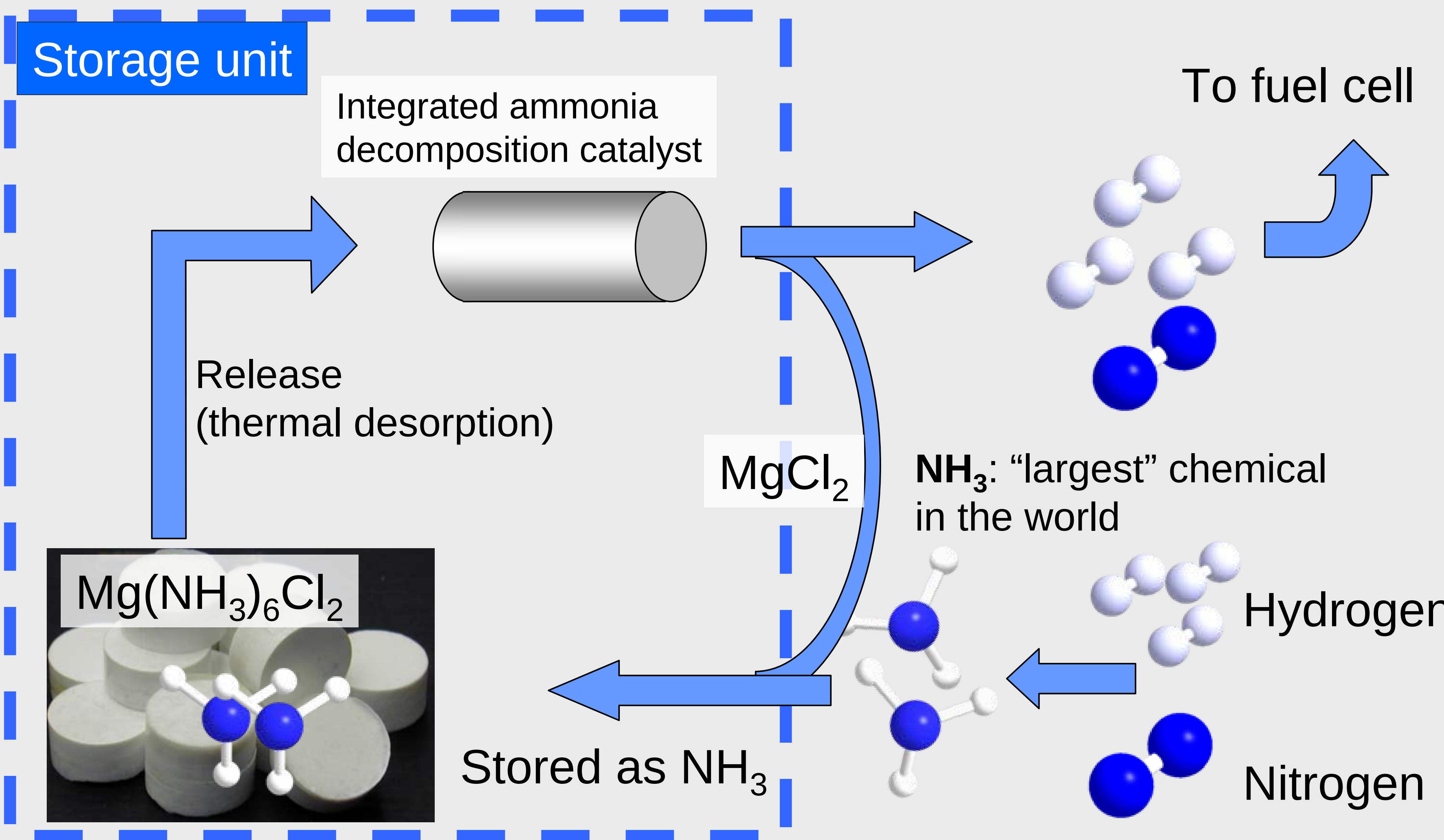
- But liq. NH_3 is normally considered too dangerous !!??

Ammonia Storage in Ammines



Christensen et al., *J. Mater. Chem*. 15 (2005) 4105.

New Concept for Energy Storage: *using Metal Ammine Complexes*

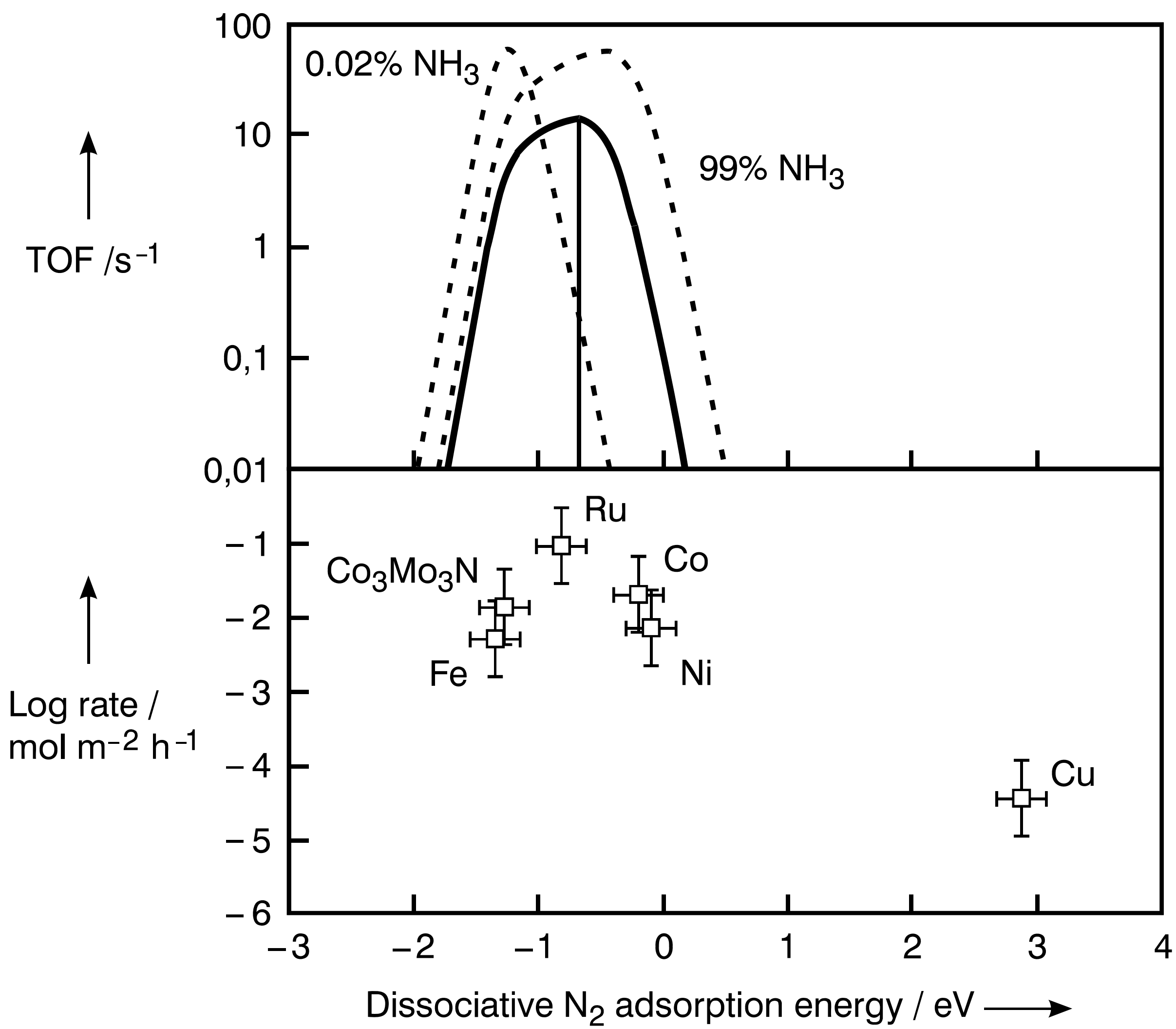


The H_2 Pathway

Reversible!

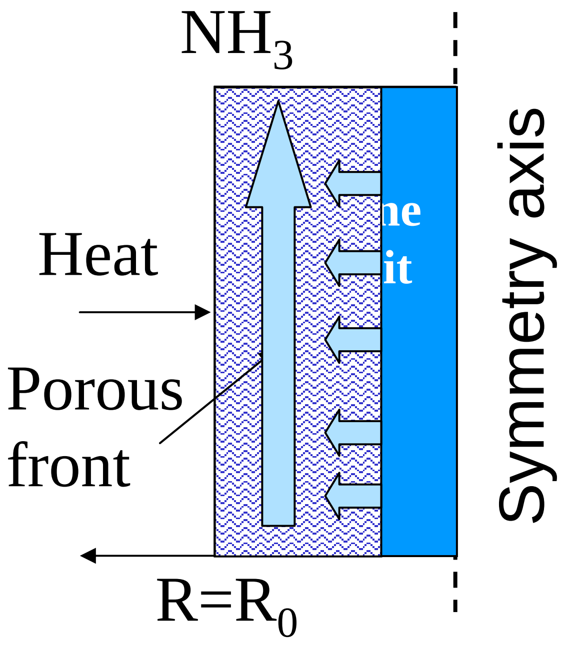
Ammonia Decomposition is Central

$$2NH_3 \rightleftharpoons N_2 + 3H_2$$



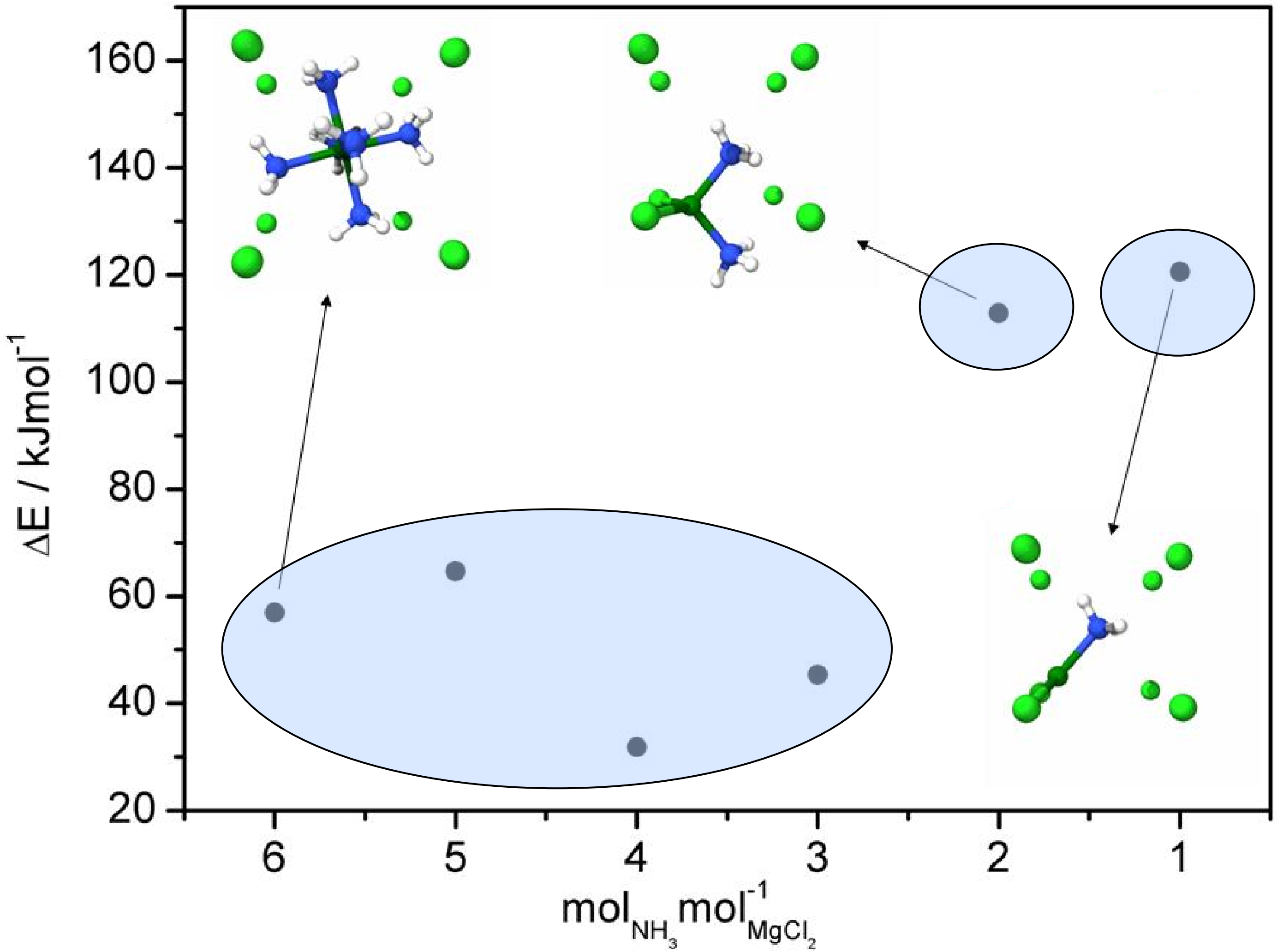
Boisen, Dahl, Nørskov, Christensen, *J. Catal*. 230 (2005) 318.

NH_3 Release from Compact Tablets: Self-generated Nanoporosity



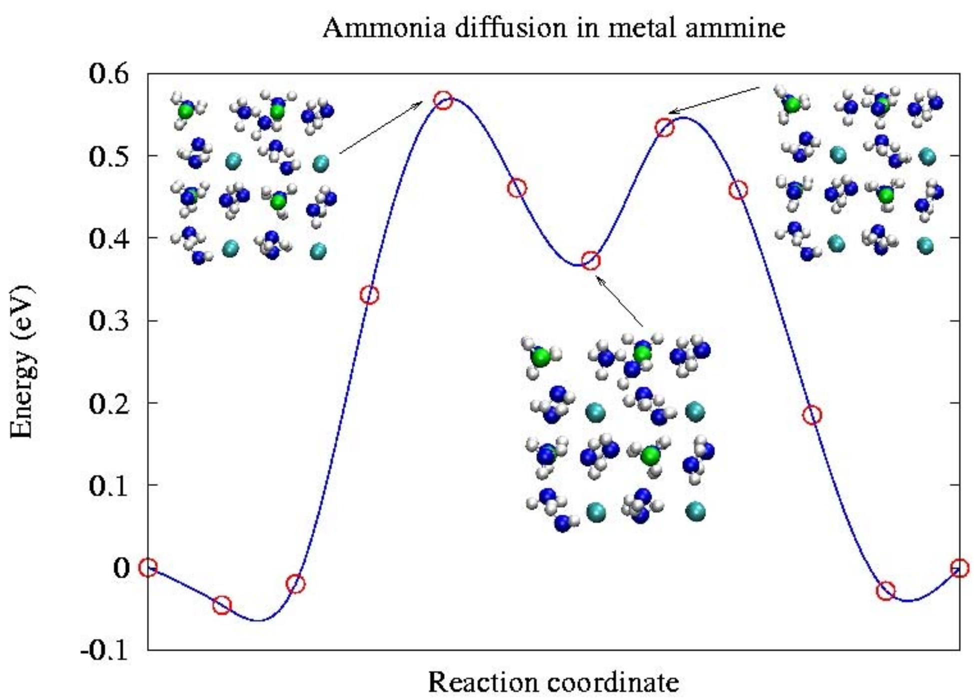
Sørensen, Johannessen, Nørskov and Christensen, *Catal. Today* 111 (2006) 140.

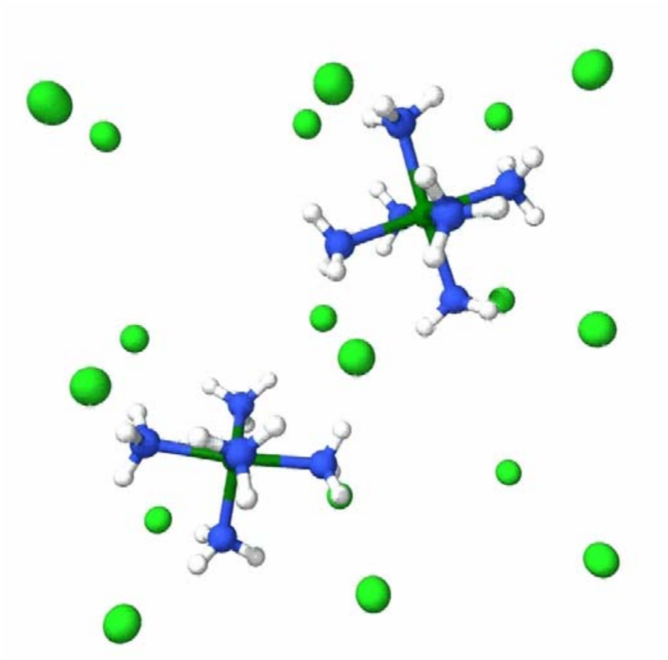
Energy Level Diagram



Hummelshøj, Sørensen, Kustova, Johannessen, Nørskov and Christensen, *J. Am. Chem. Soc.* 128 (2006) 16.

Indirect Solid Storage – $Mg(NH_3)_6Cl_2$

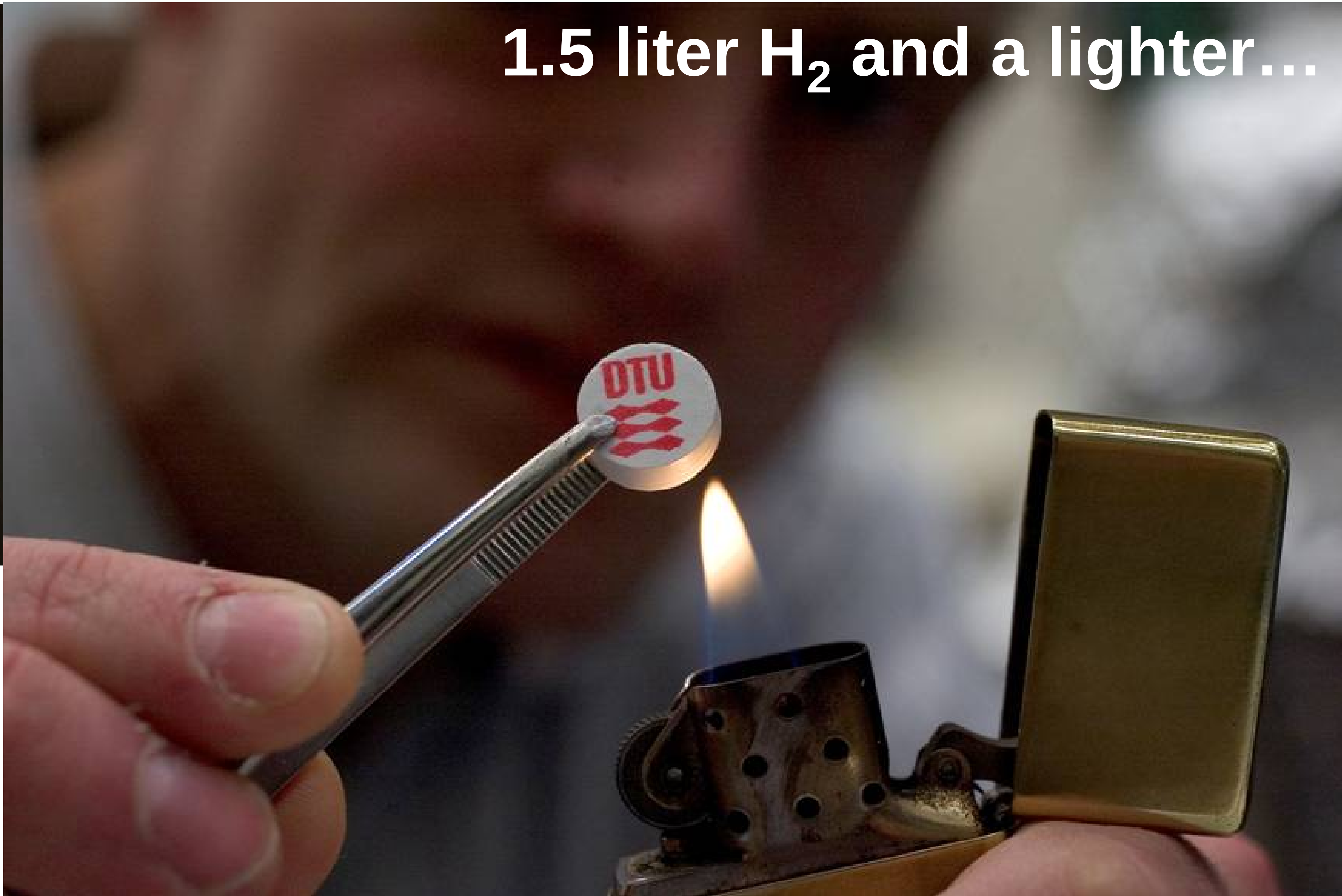




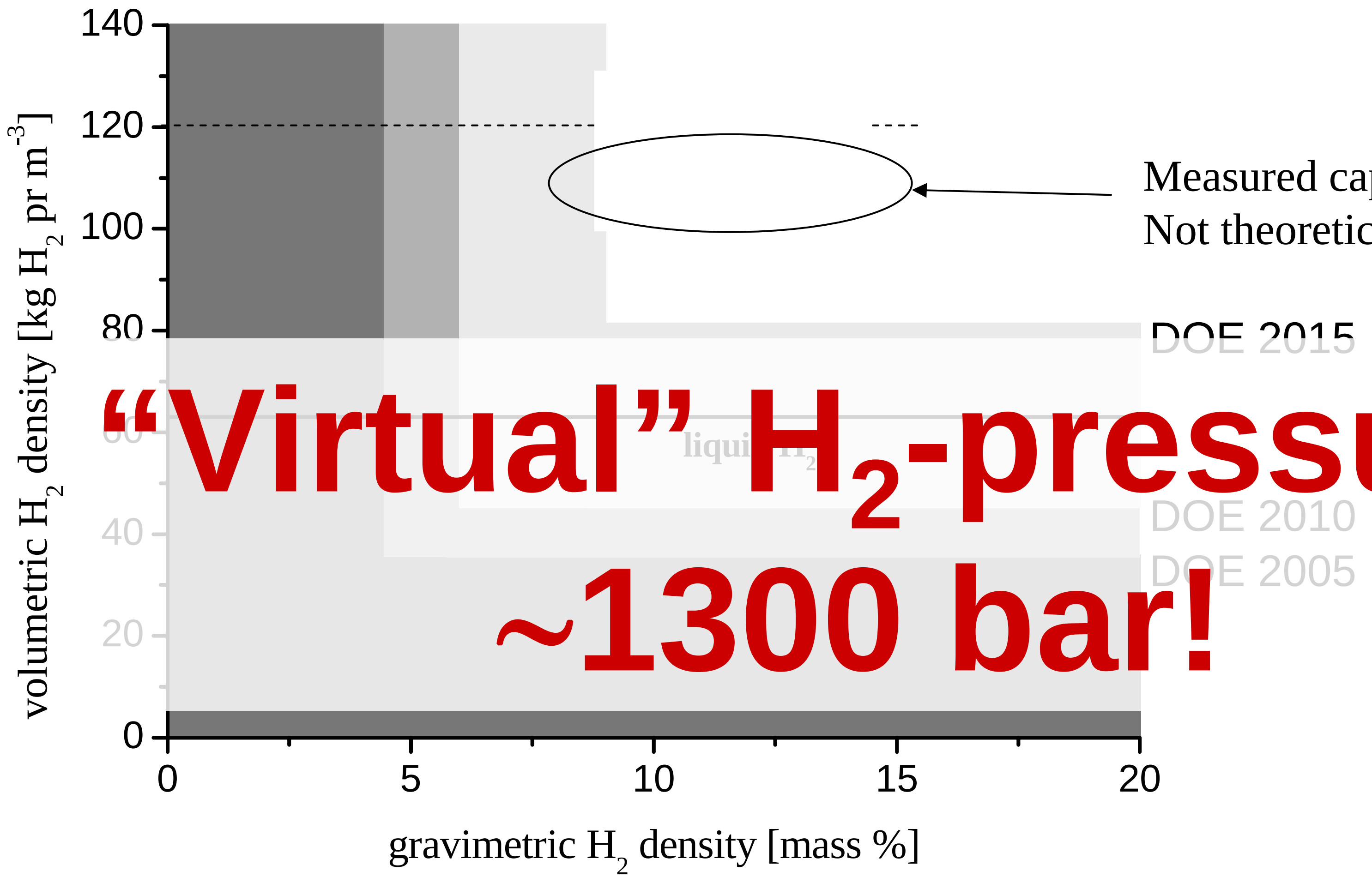
	E_*desorp*	E_*migr.*	E_*H-vac*
$Mg(NH_3)Cl_2$	~ 0.5 eV	<0.6 eV	~ 0.5 eV

Hummelshøj, Christensen, Honkala, Nørskov, unpublished

Safe Hydrogen Storage!



Details on the Hydrogen Capacity



“Virtual” H_2-pressure:

~1300 bar!

2nd Generation Prototype – Integrated NH_3 Decomposition

Insulate the decomposition reactor with the storage material…

Compact H_2-Producing System

Integrated NH_3-decomp reactor

$H_2 + N_2$

$H_2 + N_2$

Traces of NH_3: Absorption in degassed salt (< 10ppm NH_3)

μ-reactor for production of H_2:
Sørensen, Nielsen, Jensen, Hansen, Johannessen, Quaade, Christensen, *Catal. Comm.*, 6 (2005) 229

Summary

Current status

- High demonstrated density
  - **9.1 wt% H_2; 108 kg H_2/m^3**
- Reversible
- Fast release kinetics
- Simple to handle in open atmosphere
- Inexpensive (ca. 0.5 €/kg)
- CO_2-free energy carrier

On-going work

- Heat management
  - NH_3-decomposition reactor
- Purification
  - for PEM-*FC*
- Packaging/recycling

Thank you for your attention