UNIVERSITY OF BIRMINGHAM

Hydrogen Production and Storage

Dr David Book
School of Metallurgy and Materials

8th July 2011

www.hydrogen.bham.ac.uk

University of Birmingham Hydrogen and Fuel Cell Research

Chemical Engineering

Prof. K. Kendall

SOFC & Nanotechnology

Dr. B.G. Pollet

PEMFC, Electrocatalysts, Electrochem, MEA, Stack, System Integration
www.polletresearch.com

Drs. W. Bujalski & A. Dhir

Hydrogen Genaration

Dr. J. Wood

Catalysis

Drs. G. Leeke & R. Santos

Hydrogen production & Biorefining of Biomass using Supercritical Water

Dr Bushra Al-Duri

Hydrogen production using Supercritical Water Gasification

Metallurgy & Materials

Dr. D. Book

Solid-state Hydrogen Storage, Hydrogen Separation Membranes, Hydrogen Processing of Materials

Dr. A. Walton

Solid-state Hydrogen, Storage Materials & Hydrogen Processing of Materials

Prof. R. Harris & Dr. A. Bevan

Hydrogen Fuel Cell System Integration & Solid-state Hydrogen Storage

Dr. J.D. Speight

Hydrogen Separation Membranes

Dr. A.J. Davenport

Corrosion of Metallic Bipolar Plates

Chemistry

Dr. P. Anderson

New Materials for Hydrogen Storage and Delivery

Dr. P. Slater

Materials for SOFC

Prof. J.A. Preece

Nanomaterials for Fuel Cells

Prof. R. Johnston

Fuel Cell Catalysts Modelling

Prof. C. Greaves

Cathode Materials for SOFC

Biosciences

Prof. L. Macaskie & Dr. M. Redwood

Bio-Hydrogen Production

Electrical, Electronic & Computer Engineering

Dr. S. Hillmansen & A. Hoffrichter

Hydrogen Railway Research

Mechanical Engineering

Prof. K. Jiang

Nanotomography for Porous Fuel Cell Materials

Prof. M.L. Wyszynski

Hydrogen Engines

Social Policy

Drs. S. Connor & D. Toke

Communication and Legitimacy of Policy

Economics

Prof. R.J. Green

Energy Policy, Techno-economics

Geography, Earth & Environmental Sciences

Dr. D. van der Horst

Non-technical Barriers to Energy Transition

Physics

Prof. R. E. Palmer

Hydrogen Production via Photocatalysis

Mathematics

Prof. S. Decent & Dr D. Leppinen

Modelling of SOFC & PEMFC

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www. hydrogen.bham.ac.uk
www.fuelcells.bham.ac.uk
www.polletresearch.com

32 Staff/50 PhDs/12 Postdocs

Compiled by Dr Bruno G. Pollet – b.g.pollet@bham.ac.uk

(1) Hydrogen Production

Efficient Bio-H_2

Organic Wastes
110 M tonnes pa (WRAP, UK)

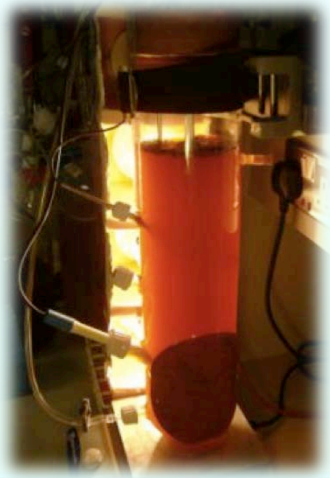
Hydro-thermal hydrolysis

Sugars

Dark fermentation

Organic acids

Photo- fermentation



H_2

Clean Power

Dr Mark Redwood, Rafael Orozco, Prof Lynne Macaskie

Biosciences
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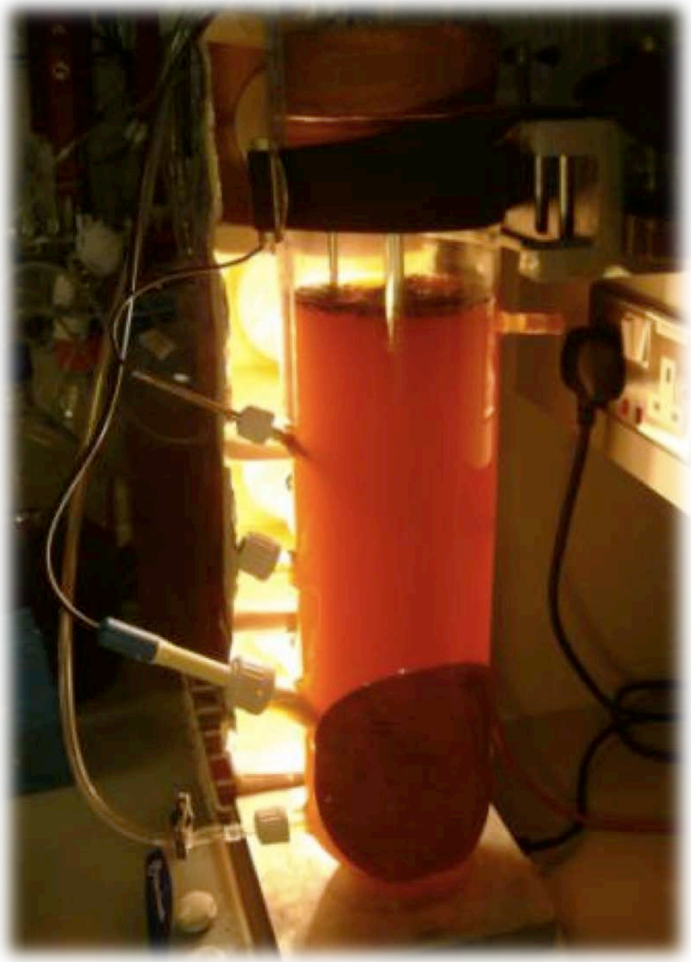
Photofermentation

- Organic acids → $H_2 + CO_2$
- Light-driven (sunlight)
- *Rhodobacter sphaeroides*
  - Strain O.U.001 (WT)
  - Photobioreactor (PBR)
- High yield, broad range
  - e.g. Lactate → 6 H_2
- H_2 produced by Nitrogenase enzyme
  - Very sensitive to NH_4^+
  - Can use wastes with high C/N



Biosciences
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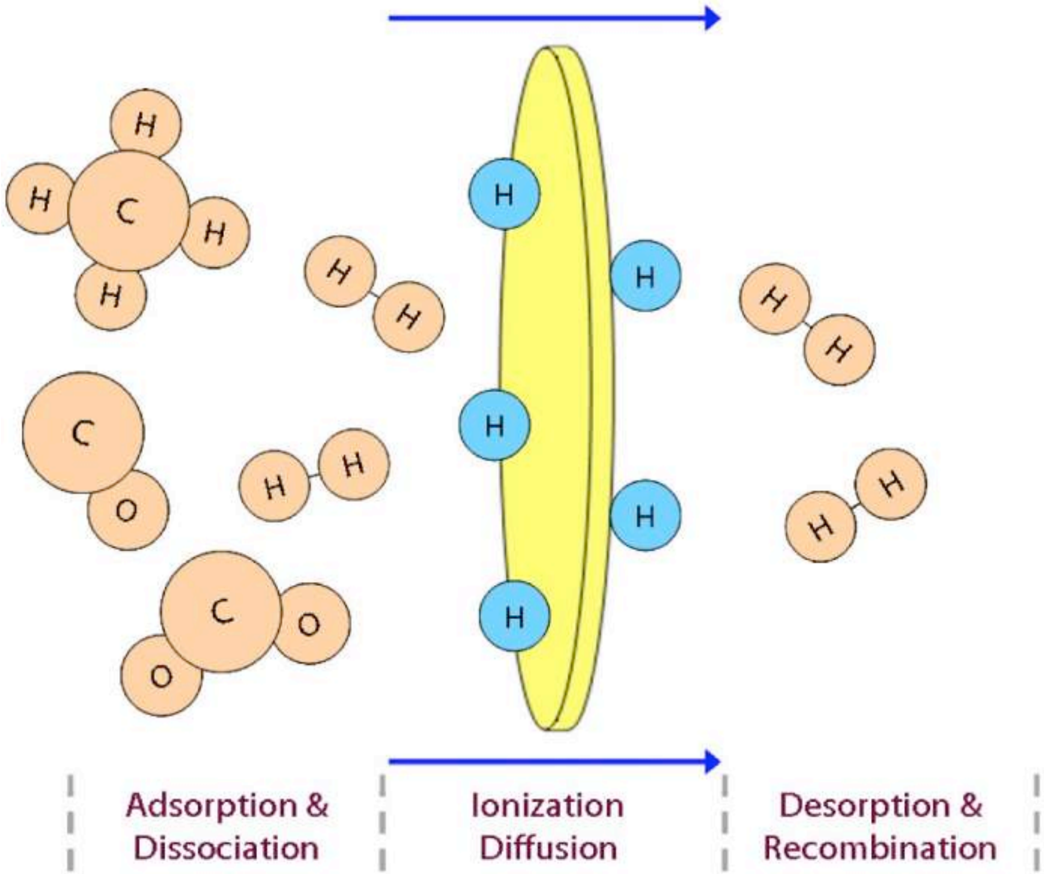
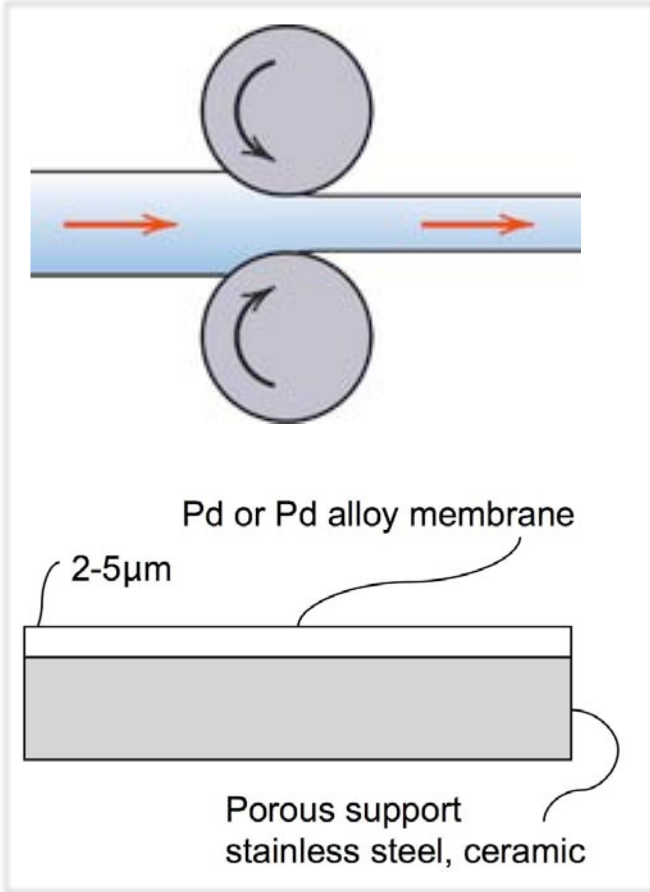
Prof Lynne Macaskie
(L.E.Macaskie@bham.ac.uk)

(2) Hydrogen Separation

- "*Pd membranes provide < 1 ppb purity with any gas quality*" - JM



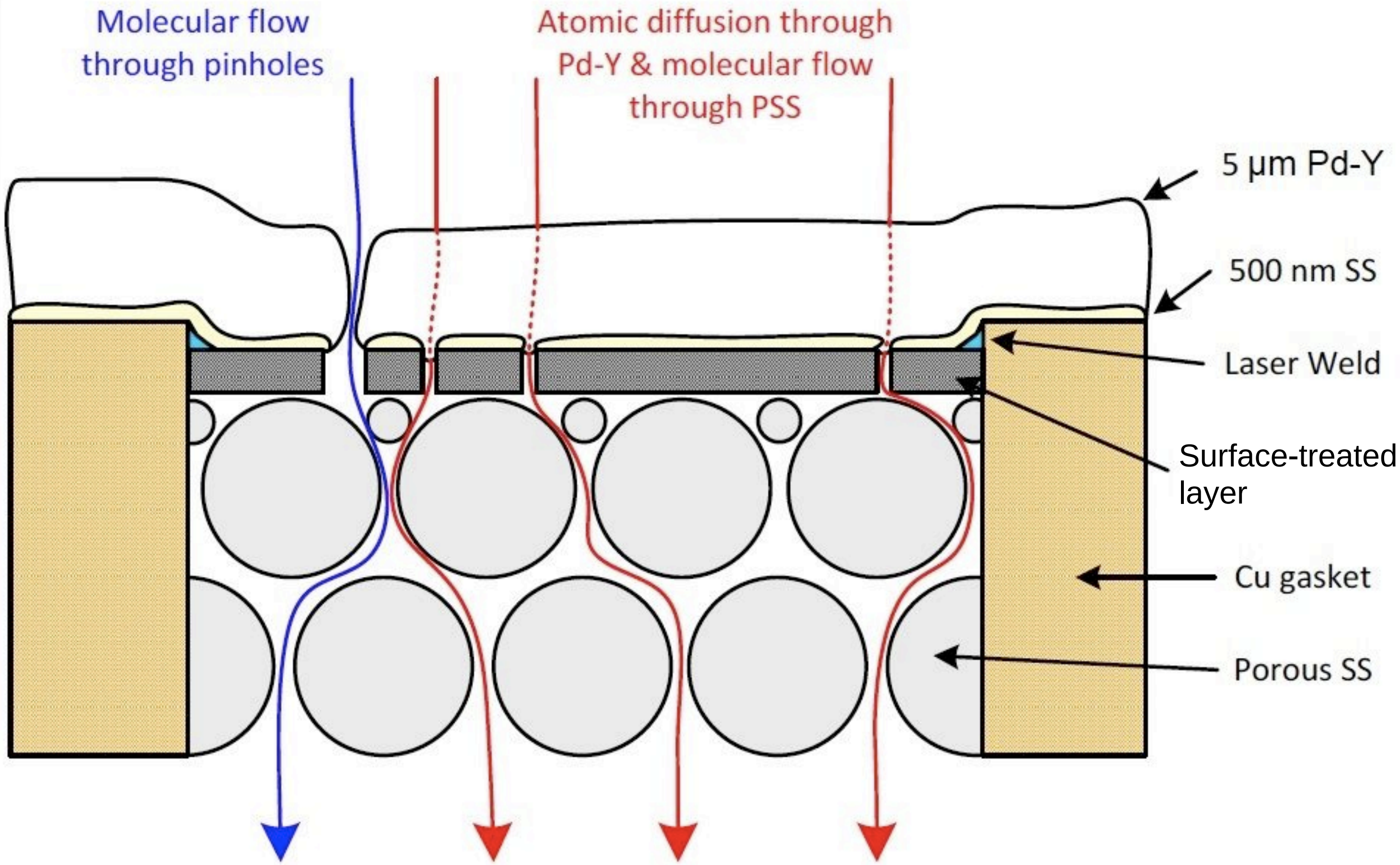


- PEM Fuel Cells are poisioned by: CO > 10 ppm, and Sulphur at ~1 ppb
- Combined hydrocarbon reformation / separation reactors

(1) Novel Pd-Y-based alloys (2) Non-Pd amorphous alloys

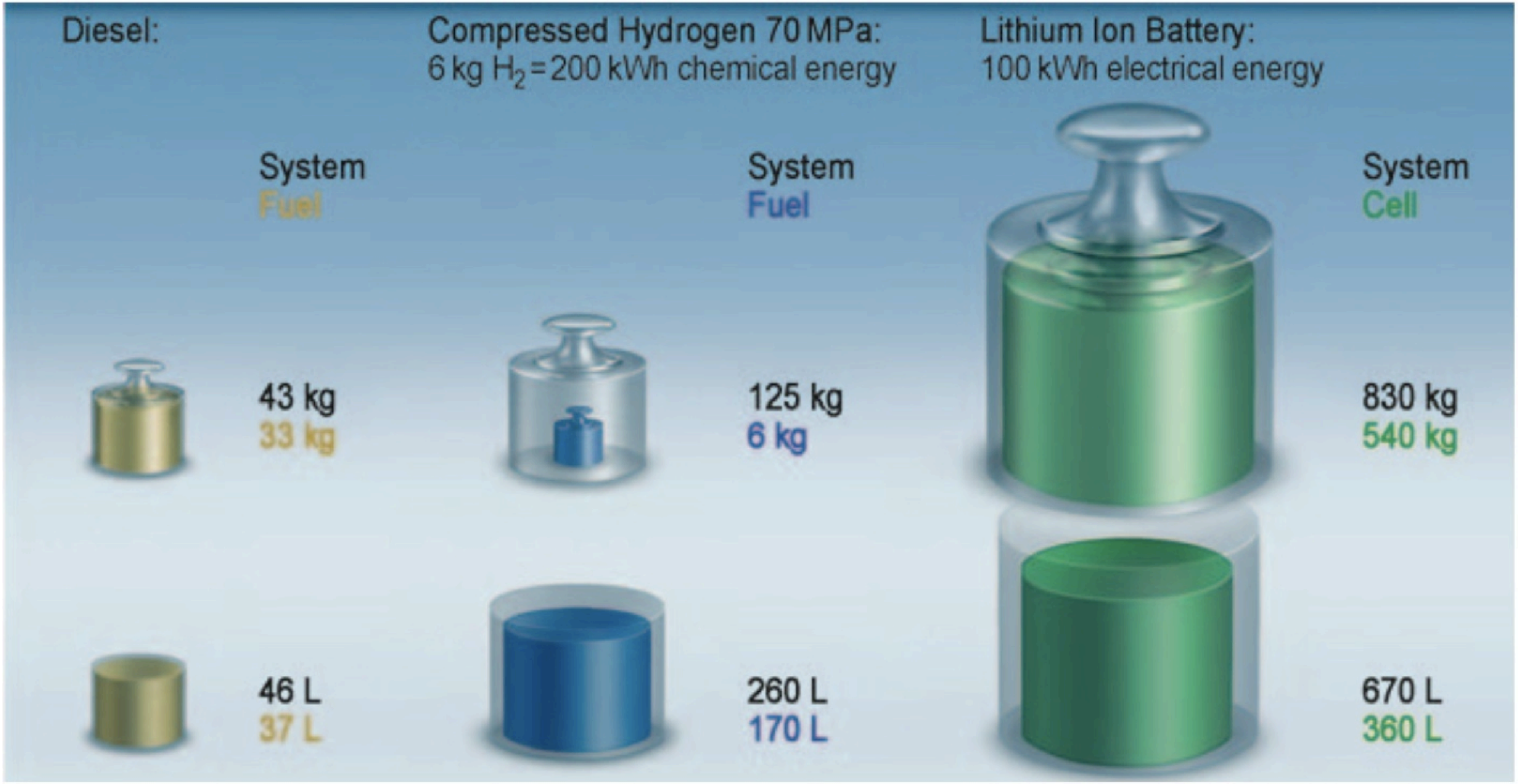
(3) Thin-film / PSS composites constructed

Magnetron Sputterer



- TSB HYPNOMEM project
- Sean Fletcher, PhD Thesis, University of Birmingham (2010)

Weight of energy storage systems to take a car 500 km

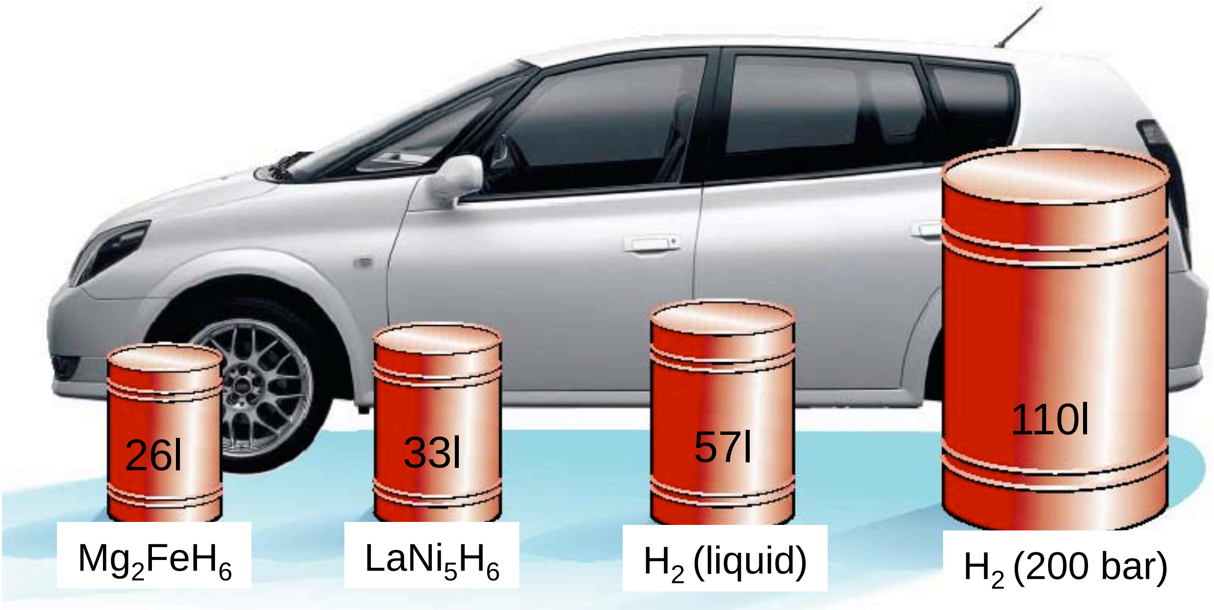


"*Chemical and Physical Solutions for Hydrogen Storage*", U. Eberle, M. Felderhoff, F. Schüth, Angew. Chem. Int. Ed. <u>48</u>, pp.2 – 25, 2009

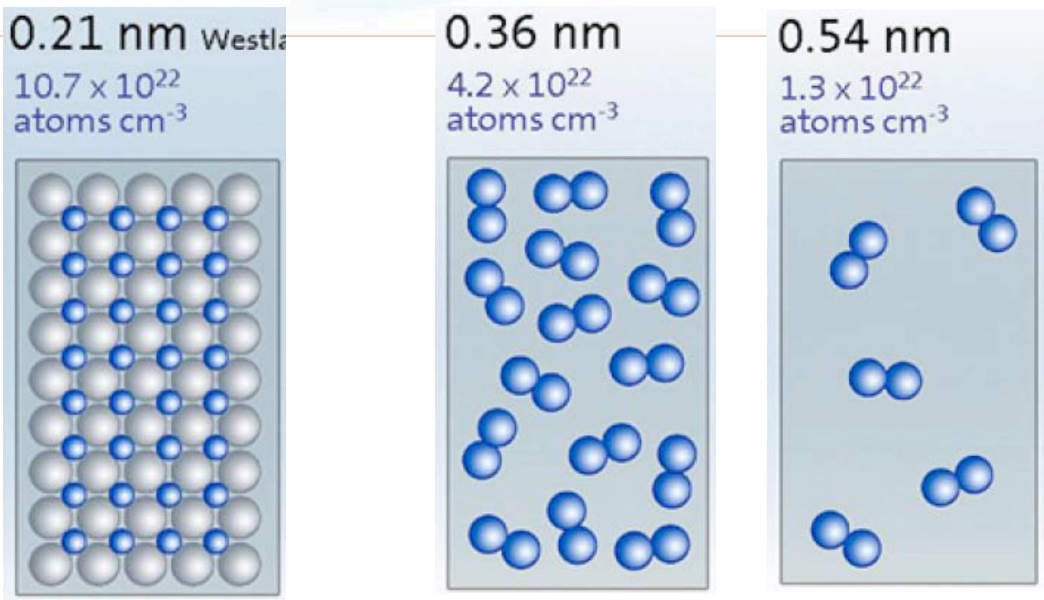
(3) Hydrogen Storage

4 kg hydrogen

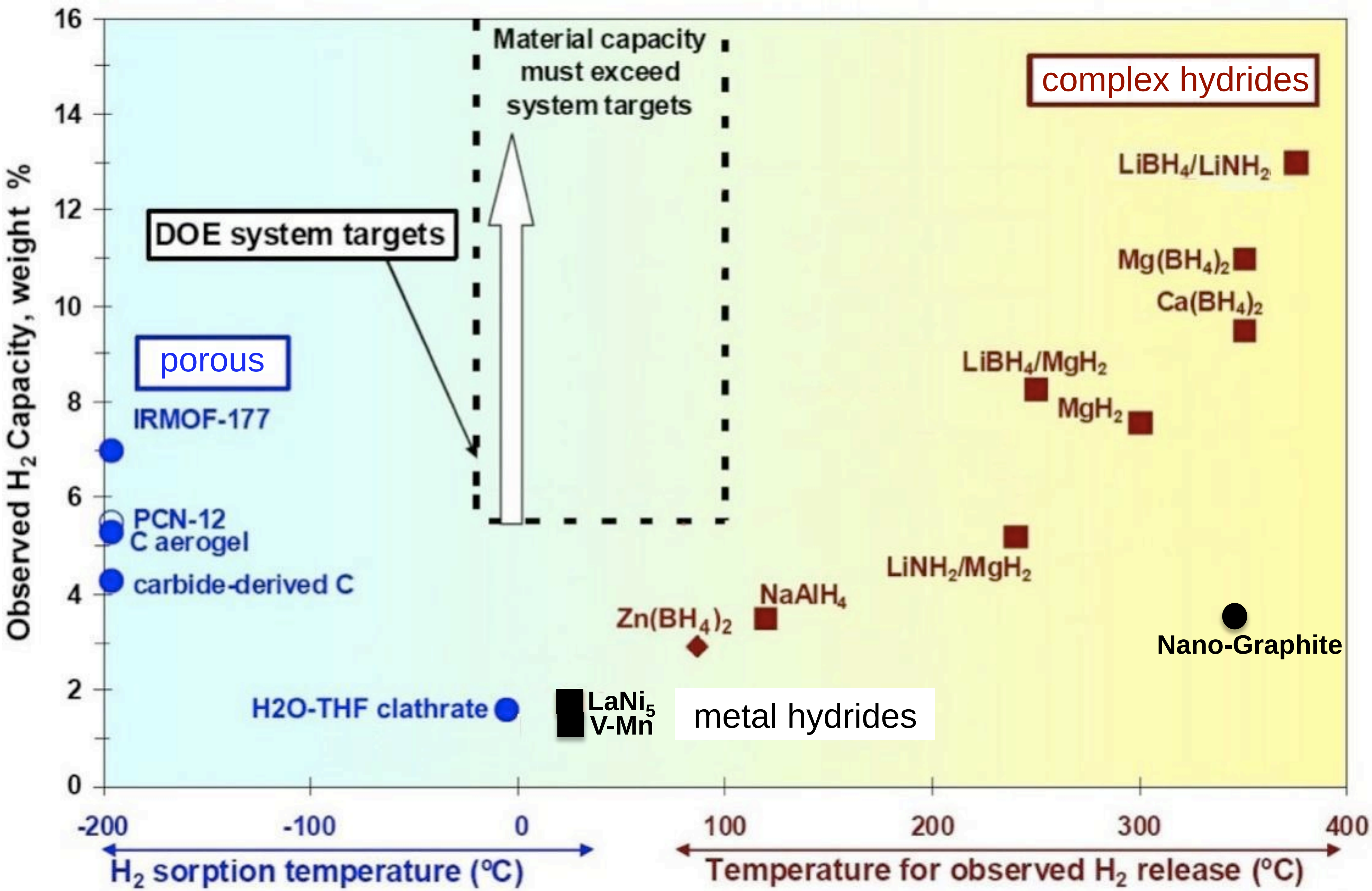
Louis Schlapbach & Andreas Züttel, NATURE, 414, p.353, (2001)



The **volume** of compressed hydrogen tanks can be greatly reduced by using metal hydride powders



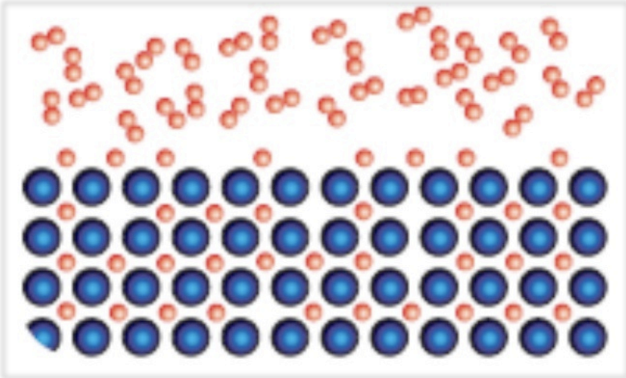
R. von Helmolta, U. Eberle, J. of Power Sources 165 (2), pp.833-843, 2007



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

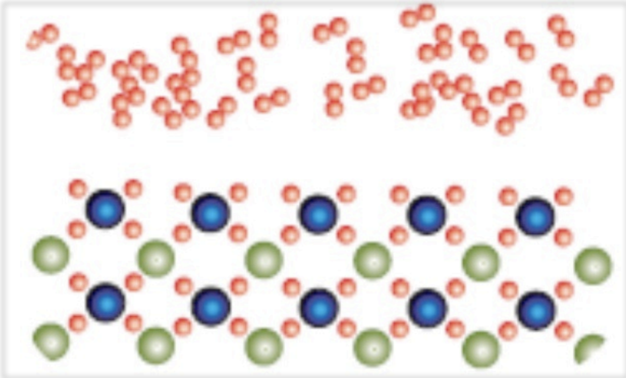
(Data edited 2011)

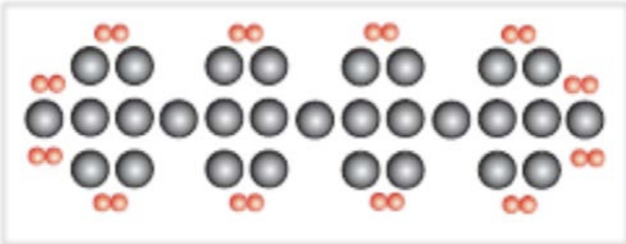
Hydrogen Storage Research



Figures from: Ned Stetson, 2010 DOE Annual Merit Review, Washington, 8/6/10)

- Metal Hydrides
  - V-Mn alloys – high pressure *(M&M)*
  - Metal hydride store & compressor design
- Magnesium Alloys
  - Ball-milling & catalysis
  - Thin-film multilayers
  - ★ Rapid solidification
  - Borohydride surface treatment *(Chemistry)*
  - TEM of MgH_2 → Mg transition (M&M Microscopy)
- Complex Hydrides
  - ★ Novel Amide-borohydrides *(Chemistry)*
  - Novel TM borohydrides
  - ★ In situ characterisation techniques
- Nanocarbons - ball-milling
- Porous Materials
  - Synthesis of zeolites & MOFs *(Chemistry)*
  - Variable temp H_2 sorption measurements





3 Examples: (i) Novel Complex Hydrides

In Chemistry, work is centred on crystal engineering of light metal complex hydrides

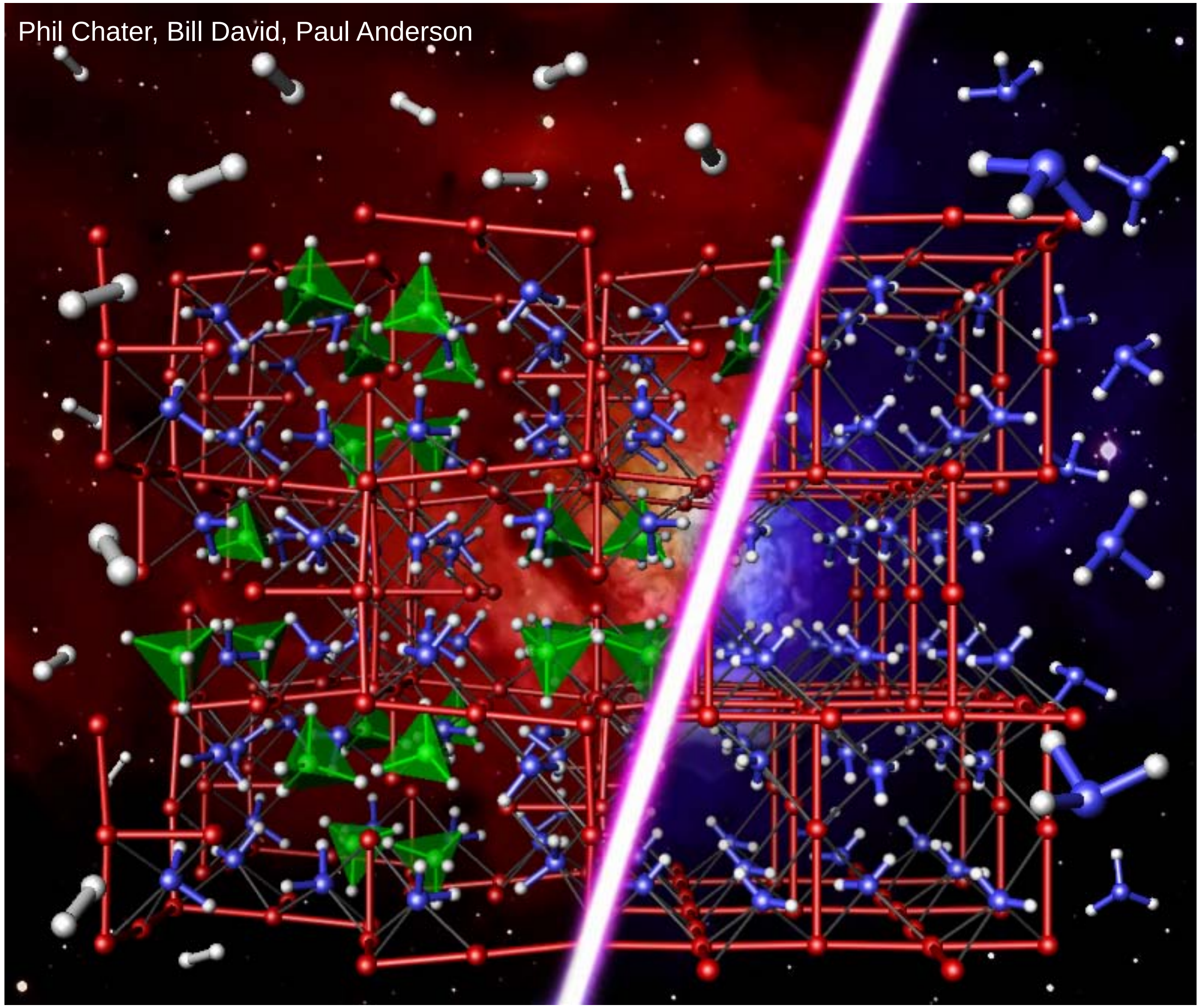
$LiNH_2$ and $LiBH_4$ powders ground together under Ar, then heated to 190°C.

➔ Adding BH4 into the amide structure, changes the primary decomposition pathway away from NH_3 in favour of H_2

Heating this compound to 250-300°C gives ~6 wt% H_2

• Other new compounds: $Na_2BH_4NH_2$, $MgBH_4NH_2$, $Li(NH_3)BH_3NH_2BH_3$ and $NaBH_3NH_2BH_3$

$Li_4BH_4(NH_2)_3$ *$LiNH_2$*



Lithium amide–borohydride *Lithium amide*

Dr Paul Anderson (p.a.anderson@bham.ac.uk)

Chemistry
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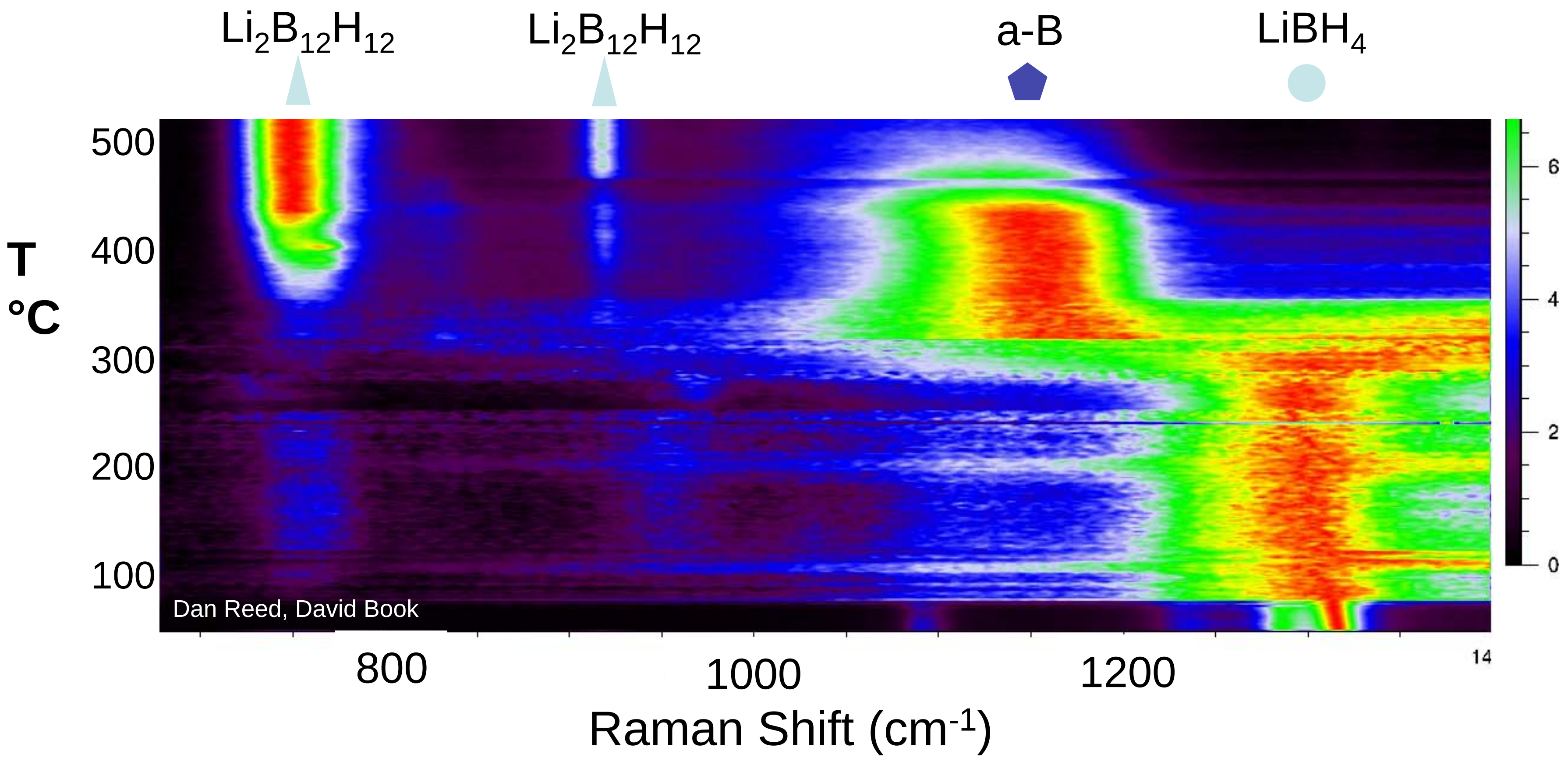
(ii) In situ characterisation of hydrides

- XRD, Raman, FTIR (Chemistry), DSC, TGA-TPD, Confocal Microscopy

e.g. In situ Raman spectroscopy of the decomposition of lithium borohydride:



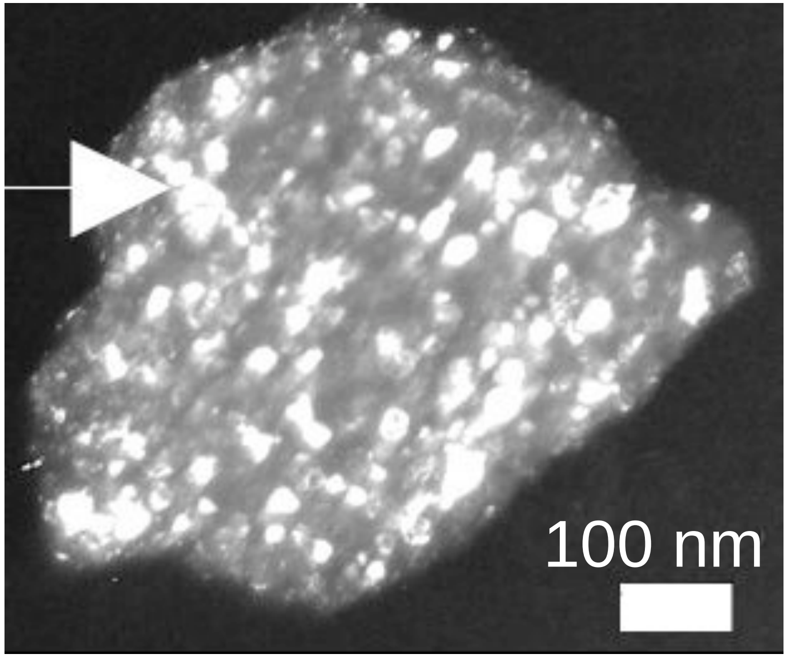
Able to identify in situ intermediate amorphous phases.

→ could help design complex hydrides that re-absorb H_2 more easily

(iii) Nano-Magnesium Alloys

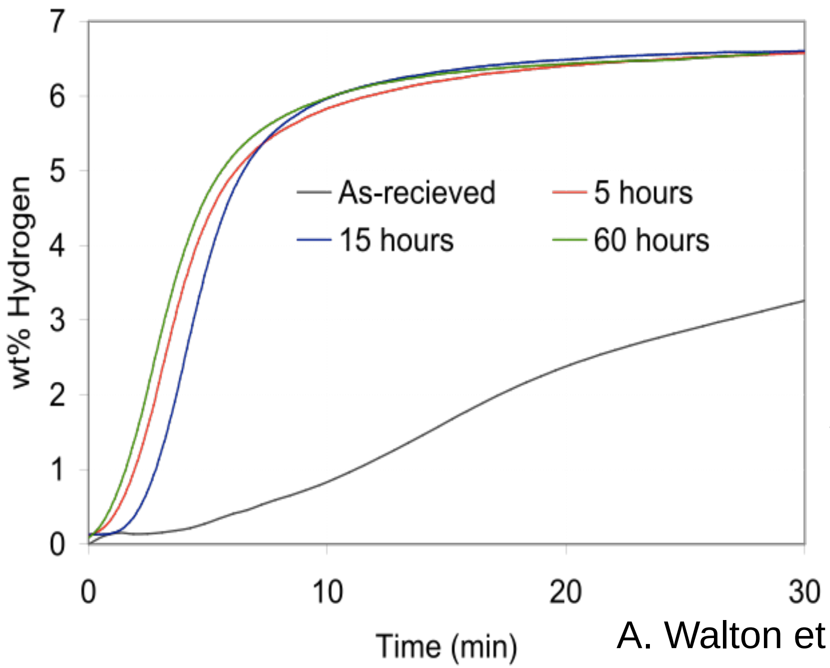
Magnesium can store 7.6 wt% hydrogen, but needs to be heated to ~300°C and H_2 sorption is slow

Mg alloys produced by a range of techniques:
- Ball-milling (*below & right*)
- Doping with PGMs (JM) or borohydrides (Chemistry)
- Thin-film multilayers
- Rapid Solidification



TEM (60 hrs milled)

B. Paik et al, PhD Thesis, Univ Birmingham (2008)



Hydrogen absorption
300˚C,10 bar

A. Walton et al, Presentation at MH2004

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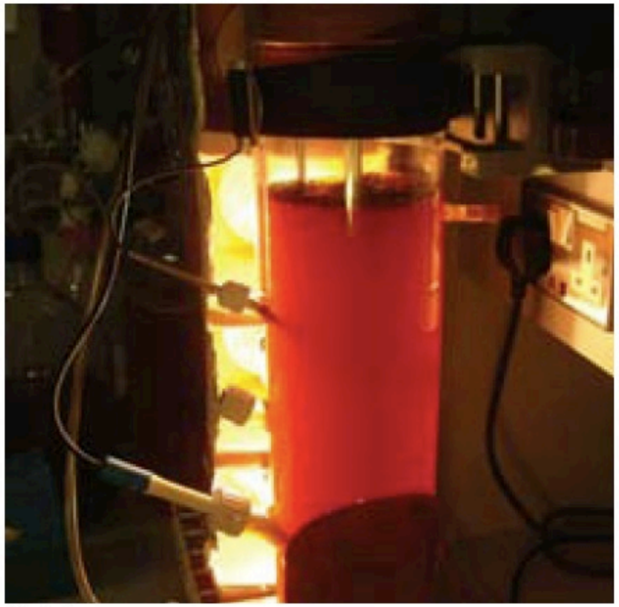
Production → Storage → Application


Biohydrogen reactor


Metal hydride storage


Hydrogen fuel cell vehicle

Economics

Hydrogen energy R&D (& postgraduate teaching) at Birmingham, involves research groups from across the campus, including: Engineering & Physical Sciences; Life & Environmental Sciences; and Social Sciences.

www.hydrogen.bham.ac.uk www.fuelcells.bham.ac.uk www.ierp.bham.ac.uk

Advantage West Midlands
Birmingham Science City

EPSRC

SUPERGEN
www.uk-shec.org.uk
www.supergen14.org

Technology Strategy Board

CARBON TRUST