HYDROGEN IMPLEMENTING AGREEMENT

GKSS FORSCHUNGSZENTRUM in der HELMHOLTZ GEMEINSCHAFT e.V.

IEA HIA and Hydrogen R,D&D

Dr. Martin Dornheim, Mr. Antonio García-Conde,
Dr. Bjorn C. Hauback and Ms. Mary-Rose de Valladares

ECES: Role of Energy Storage in Future Energy Systems

IEA HIA Presentation

- IEA HIA Fundamentals
- Task 22 - Introduction
- Task 22 Specifics

Working Party on Energy End-Use Technologies

- Advanced Fuel Cells
- Advanced Materials for Transportation
- Advanced Motor Fuels
- Buildings and Community Systems
- Emissions Reduction in Combustion
- Demand-Side Management
- District Heating and Cooling
- Electricity Networks
- Energy Storage
- Heat Pumps
- Hybrid and Electric Vehicles
- Industrial Energy
- Superconductivity

Working Party on Fossil Fuels

- Clean Coal Centre
- Clean Coal Science
- Enhanced Oil Recovery
- Fluidised Bed Conversion
- Greenhouse Gas R&D
- Multiphase Flow Science

Fusion Power Co-ordinating Committee

- Environmental, Safety, Economic Aspects
- Fusion Materials
- Large Tokamaks
- Nuclear Technology of Fusion Reactors
- Plasma Wall Interaction in TEXTOR
- Reversed Field Pinches
- Spherical Tori
- Stellarator Concept
- ASDEX Upgrade

Working Party on Renewable Energy Technologies

- Bioenergy
- Geothermal
- Hydrogen
- Hydropower
- Ocean Energy
- Photovoltaic Power
- Renewables Deployment
- Solar Heating & Cooling
- SolarPACES
- Wind Turbines

Cross-Cutting Implementing Agreements

- Climate Technology Initiative
- Energy Technology Systems Analysis Programme
- Energy Technology Data Exchange

Expert/Ad Hoc Groups

- CERT Advisory Group on Oil and Gas Technology
- Hydrogen Co-ordination Group
- CERT Ad Hoc Group on Science and Energy Technologies
- CERT Experts Group on R&D Priority-Setting and Evaluation

IEA HIA Tasks Since 1977

Since 1977 the IEA HIA has approved 27 tasks.

Eighteen (18) tasks completed.
Thereof more than half production related.
A half dozen focused on techno-economic, engineering and market analysis.
Remaining tasks associated with storage.

Eight tasks in current portfolio covering topics in production, storage, analysis and safety activities in hydrogen.
Soon increase of number of tasks as two new tasks in the definition phase.

HYDROGEN IMPLEMENTING AGREEMENT

IEA HIA Tasks Since 1977

1. Thermochemical Production
2. High-Temperature Reactors
3. Potential Future Markets
4. Electrolytic Production
5. Solid Oxide Water Electrolysis
6. Photocatalytic Water Electrolysis
7. Storage, Conversion and Safety
8. Techno-Economic Assessment
9. Hydrogen Production
10. Photoproduction of Hydrogen
11. Integrated Systems
12. Metal-Hydride for H_2 Storage
13. Design &Optimization Integ. Systems
14. Photoelectrolytic Production
15. Photobiological Production
16. H2 from Carbon-containing mat.
17. Solid & Liquid Storage Materials
20. Hydrogen from Waterphotolysis

Current Portfolio

18. **Integrated Systems - II**
19. **Hydrogen Safety -II**
21. **BioHydrogen - II**
22. **Fundamental & Applied H_2 Storage Materials Development**
23. **Small-Scale Reformers for On-Site H2 Supply (SSR for H_2)**
24. **Wind Energy and H2 Integration**
25. **High Temperature Processes for H_2 Production**
26. **Advanced Materials for H_2 from Waterphotolysis**
27. **Near-Market Routes to H2 by co-utilization of biomass with fossil fuel**

Hydrogen Implementing Agreement (HIA)

A collaborative research and development (R&D) program

Created in 1977 on a task-shared, "bottom-up" basis

Strategic Framework

Vision

A hydrogen future based on a clean sustainable energy supply of global proportions that plays a key role in all sectors of the economy

Mission

To accelerate hydrogen implementation and widespread utilization to optimize environmental protection, improve energy security, and promote economic development internationally while establishing the HIA as a premier global resource for expertise in hydrogen.

Strategy

To facilitate, coordinate and maintain innovative research, development and demonstration (RD&D) activities through international cooperation and information exchange

Mission:

The mission of the IEA Hydrogen Program is to accelerate hydrogen implementation and widespread utilization.

Objectives:

Technology Objective: To promote acceptance of hydrogen as an energy.

Energy Security Objective: Contribute to global energy security.

Environmental Objective: Exploit the environmental benefits of hydrogen.

Economic Objective: Develop cost-effective hydrogen energy systems that can compete in global markets.

Market Objective: Identify and overcome barriers for hydrogen's penetration into the energy and fuel markets.

Deployment Objective: Promote deployment of hydrogen technologies with important local and global energy benefits.

Outreach Objective: Advertise the benefits of hydrogen.

IEA HIA Members

June 2009

Canada
Mr Nick Beck

European Commission
Dr Marc Steen

Japan
Dr Yoshiteru Sato

Italy
Mr Agostino Iacobazzi

Iceland
Dr Agusta Loftsdottir

Lithuania
Dr Rolandas Urbonas

The Netherlands
Mr Frank Denys

France
Mr Paul Lucchese

Australia
Dr John Wright

Germany
Mr J.-F. Hake

Greece
Dr Elli Varkaraki

Turkey
Dr Alper Sarioglan

Korea Mr Kijune Kim

New Zealand Dr Steven Pearce Co Vice-Chair

Norway
Dr. Stian Nygaard

Spain
Mr Antonio Garcia-Conde
Chair

Sweden
Dr Lars Vallander

Switzerland
Dr Stefan Oberholzer

United Kingdom
Mr Ray Eaton

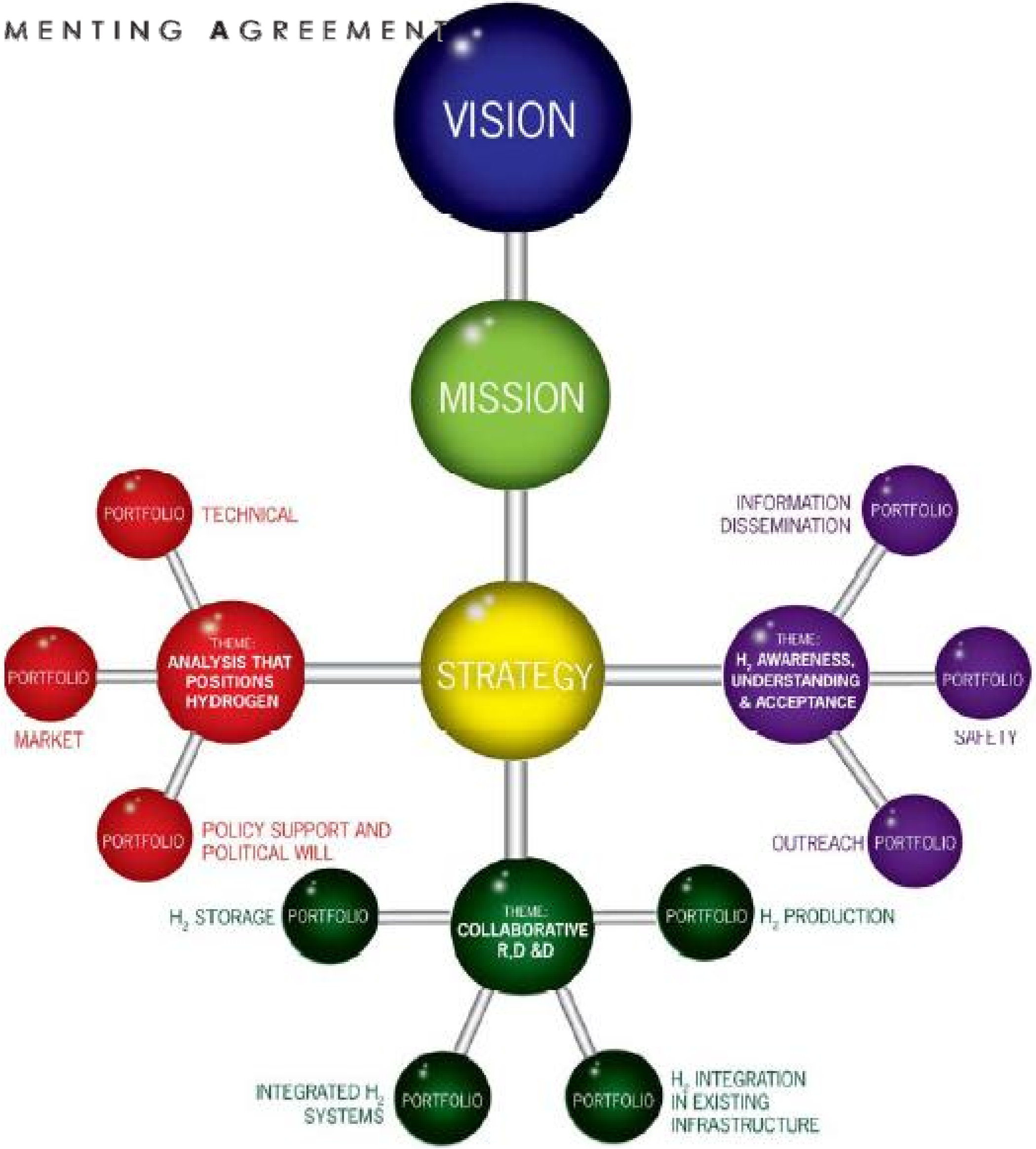
United States
Dr Carole Read

Denmark
Mr Jan Jensen
Co Vice-Chair

Finland
Dr Heikki Kotila

HYDROGEN IMPLEMENTING AGREEMENT

Strategic Framework 2009 - 2014



2009 – 2014 Themes

Collaborative R, D & D
that advances hydrogen Science and Technology

- Hydrogen Production
- Hydrogen Storage
- Integrated Hydrogen Systems
- Hydrogen integration in existing infrastructure

Analysis that Positions Hydrogen
for

- Technical progress and optimization
- Market preparation and deployment
- Support in political decision-making

Hydrogen Understanding, Awareness and Acceptance
that foster technology diffusion and commercialization

- Information Dissemination
- Safety
- Outreach

HYDROGEN IMPLEMENTING AGREEMENT

Theme:

Collaborative R,D&D

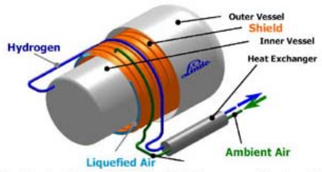
Portfolio:

HYDROGEN STORAGE

Better hydrogen storage methods

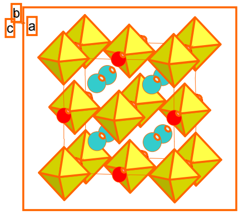
- Compressed H_2 (≤700 bar)

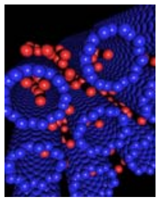
- Liquid (20K)

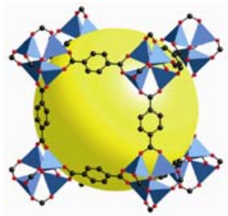


The Linde Cryogenic Tank [Diagram: Linde AG]

- **Solid materials:**



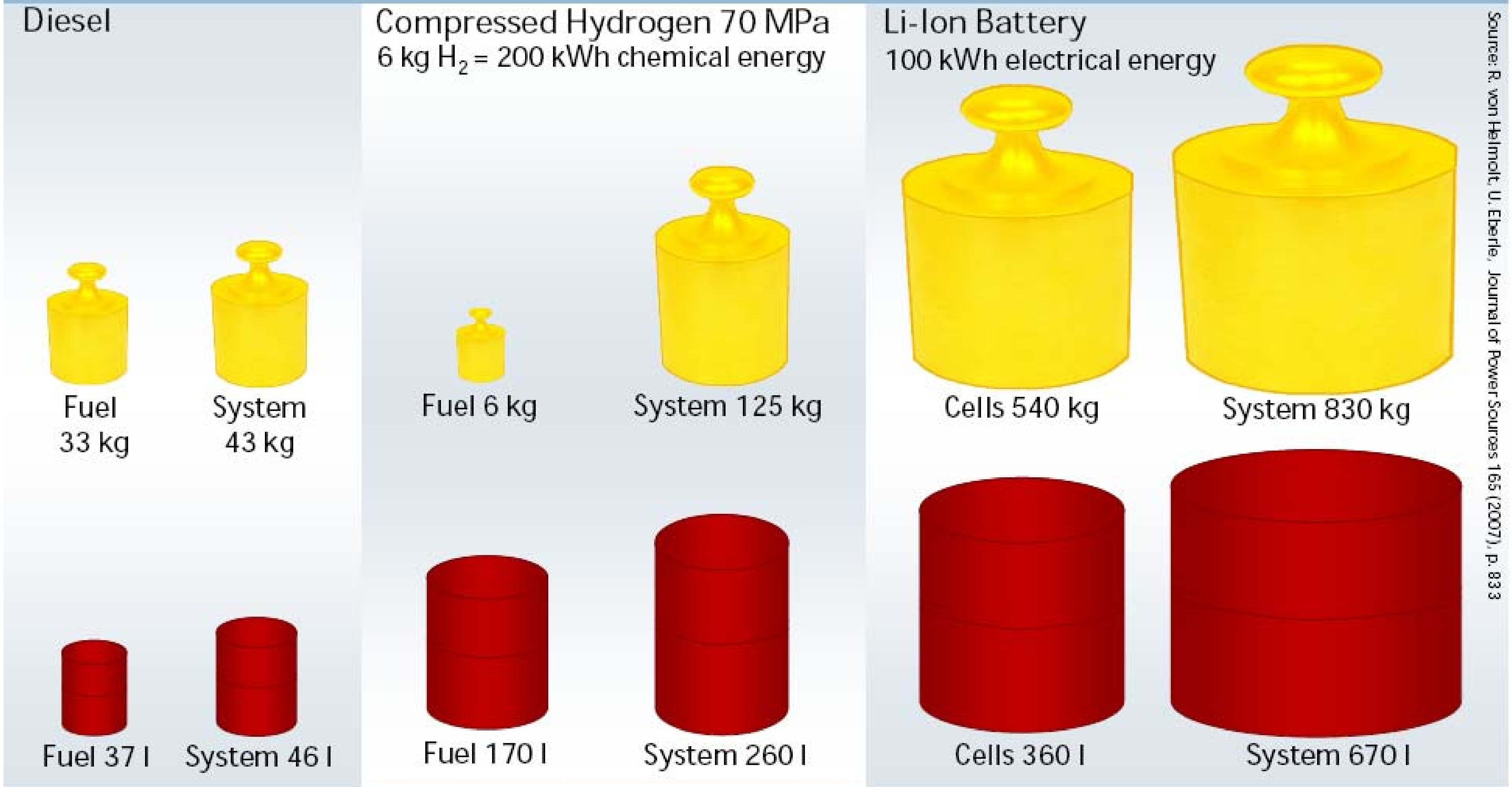




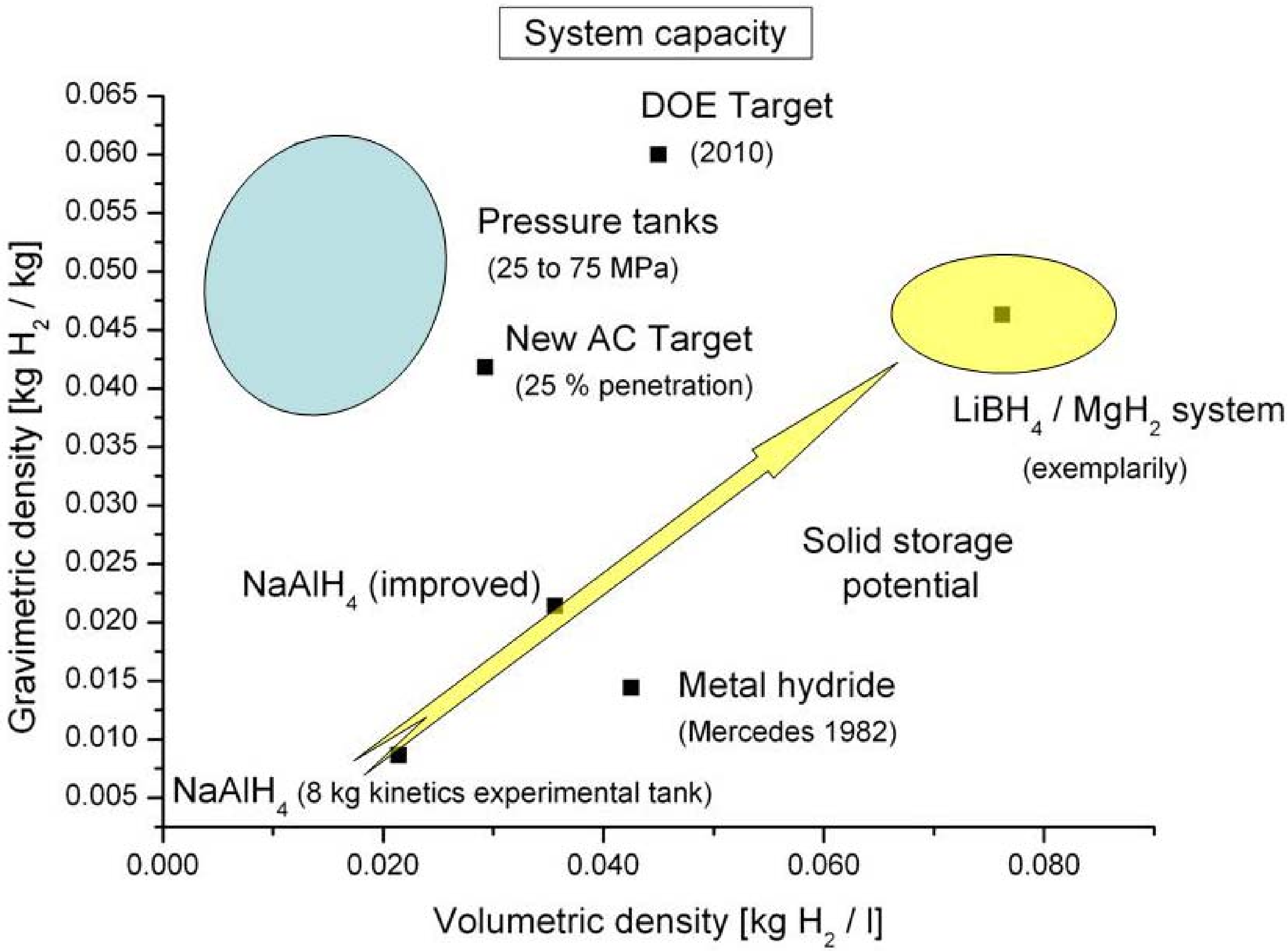
- ***Hydrides***

- ***Nanoporous materials***
  - Carbon-based
  - Microporous materials

Weight and Volume of Various Energy Storage Systems 500 km Range



Solid storage tank system development - Outlook -



Challenges

- Gravimetric and volumetric storage densities of storage material itself
  and complete tank system
- Safety
  - What happens if tank components are damaged ?
- Working temperatures compatible with envisioned applications
- Reaction enthalpy compatible with env. apps.
- Hydrogen uptake and release kinetics compatible with env. apps.
- System design
  - → total energy efficiency
- Costs

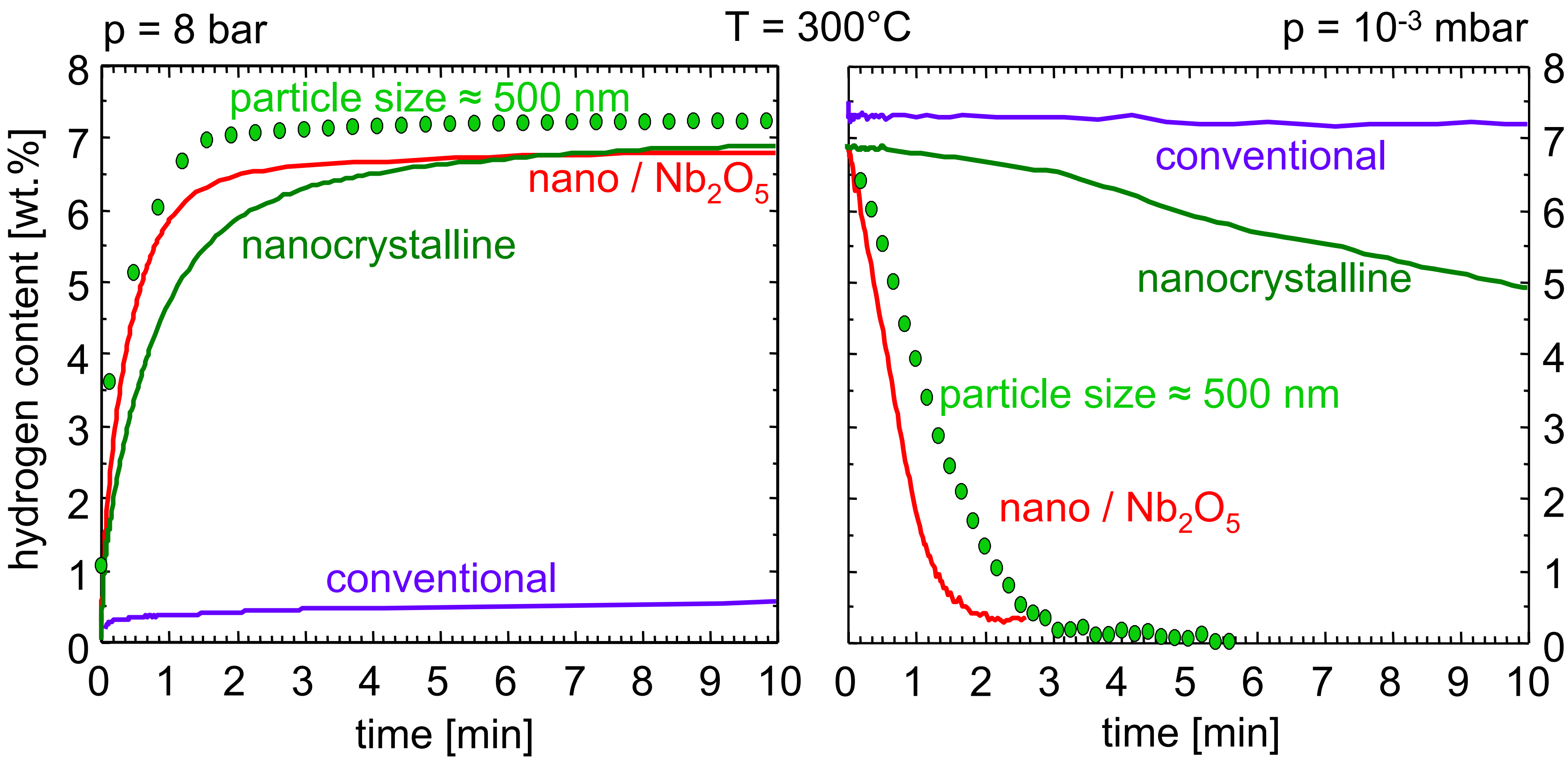
Challenges: Examples
Mg Hydride as H_2 storage material

- High gravimetric storage capacity (7.6 wt.%)
- Eights most frequent element on earth → large reserves

Major drawbacks of MgH_2 as storage material:

1. Past: Rather sluggish absorption and desorption kinetics
2. High stability of Mg-H bonds
   - High enthalpy of hydride formation
   - High desorption temperatures

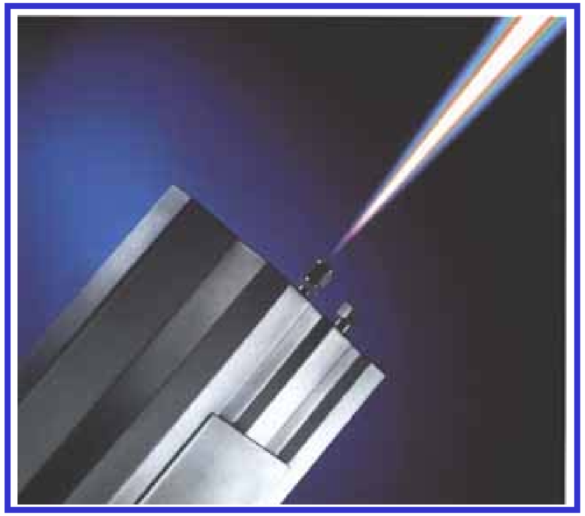
Challenges: Examples
Mg Hydride as H_2 storage material



- nanocrystallinity, catalyst, fine particle size → breakthrough in kinetics

Challenges: Examples
Mg Hydride as H_2 storage material

- → peak desorption rate up to 100 kW/kg ✓
- → max. 10 bar ✓
- → no capacity loss after 1000 cycles ✓
- → fast kinetics achieved
  - further improvement not necessary ✓
- → refuelling time 5 - 30 min → *heat transfer* ✗



<u>Challenge</u> :

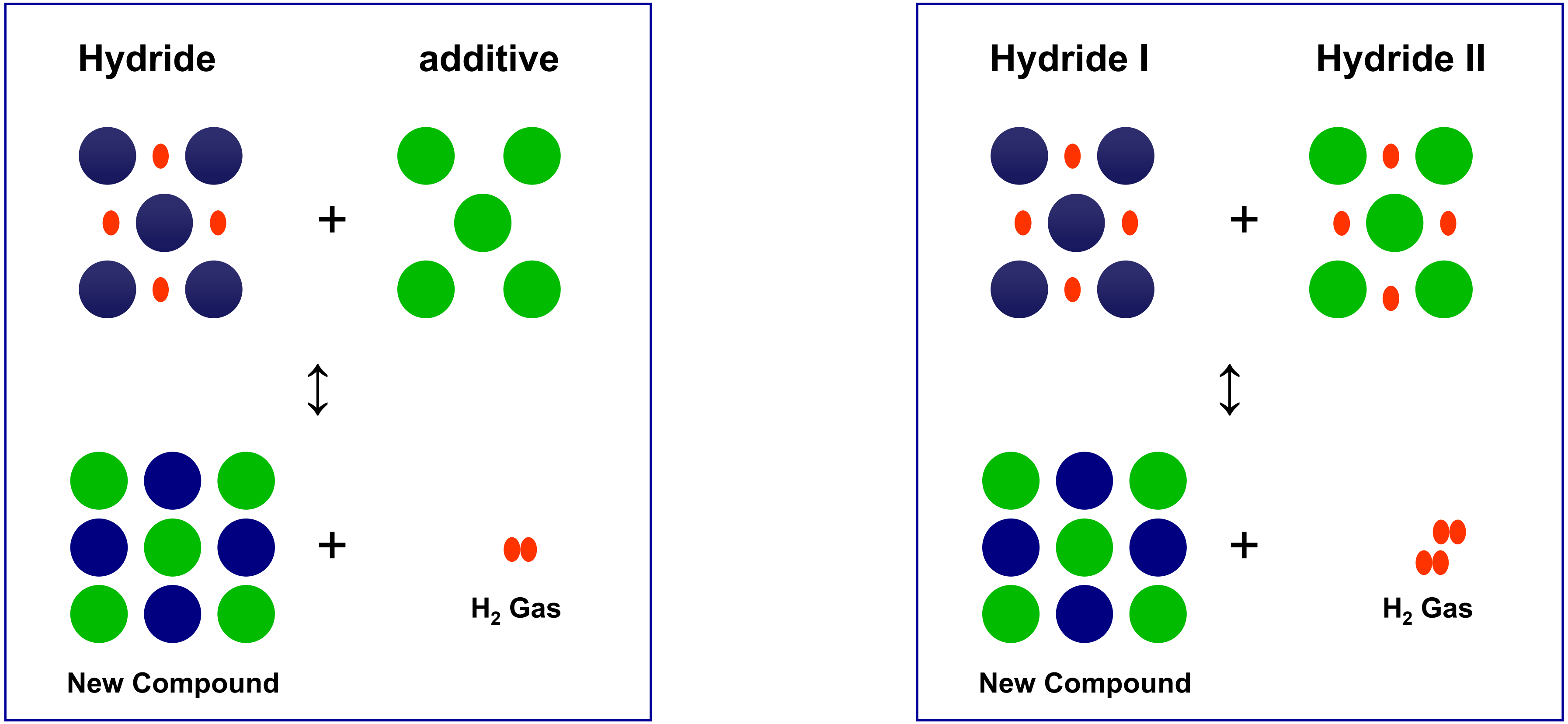
Large reaction enthalpy **(-75 kJ/mol H_2) !**

Desorption temperature $\geq$ 200°C **!**

↓

Strategies to Decrease Sorption Enthalpies of Mg-based Hydrides

Reactive Hydride Composites (RHC)



P. Chen et al. (2002),
G. Barkhordarian et al. (GKSS 2004), J.J. Vajo et al. (HRL 2004), YW. Cho (KIST 2004)

Reactive Hydride Composites (RHC)

$$LiNH_2 + 2LiH \leftrightarrow Li_2NH + LiH + H_2 \leftrightarrow Li_3N + 2H_2$$

P. Chen et al., *Nature* 420 (2002) 302-304.

$$Mg(NH_2)_2 + 2\ LiH \leftrightarrow Li_2Mg(NH)_2 + 2H_2$$

T. Xiong, et al., *J. Alloys and Compds.* 398 (2005) 235-239.

$$MgH_2 + 2\ LiBH_4 \longleftrightarrow MgB_2 + 2\ LiH + 4H_2$$

ΔH = - 46 kJ/mol H_2
11.5 wt.%!!

$$MgH_2 + 2\ NaBH_4 \longleftrightarrow MgB_2 + 2\ NaH + 4H_2$$

ΔH = - 25- 35 kJ/mol H_2
8.3 wt.%

$$MgH_2 + Ca(BH_4)_2 \longleftrightarrow MgB_2 + CaH_2 + 4H_2$$

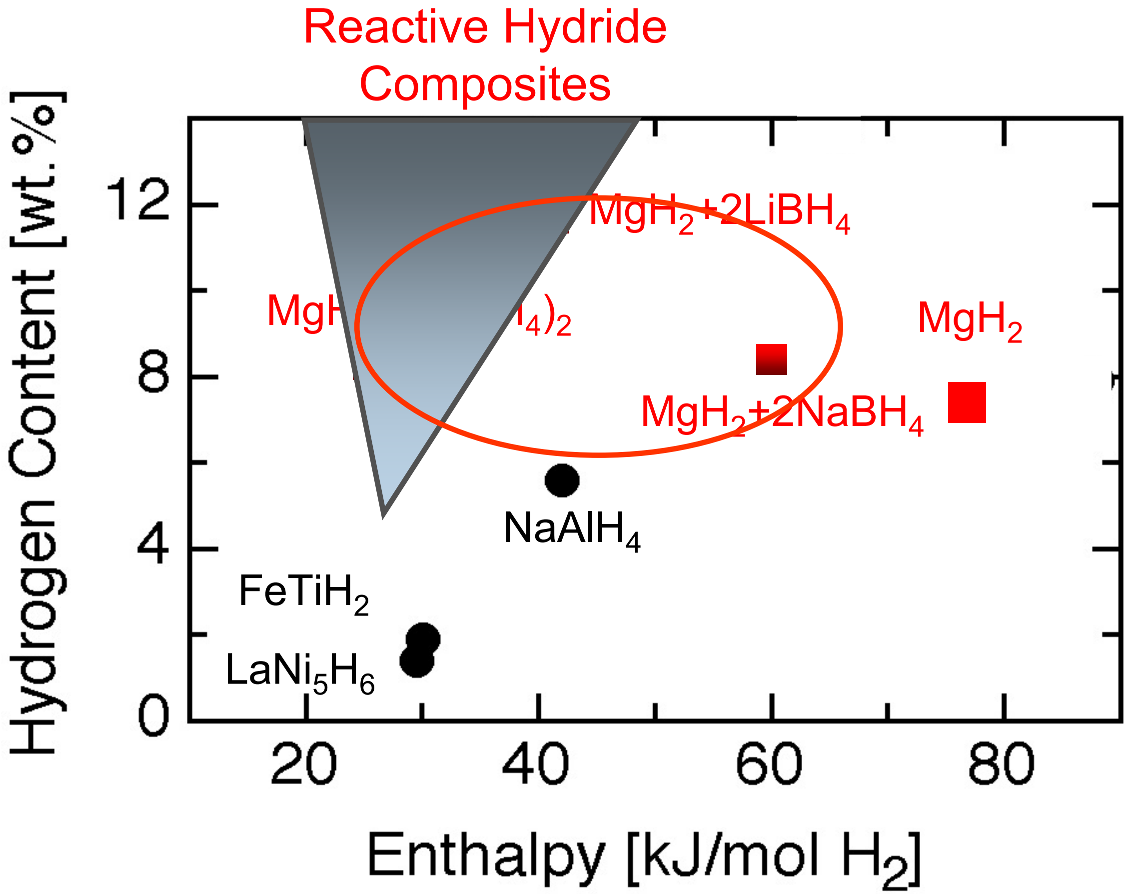
ΔH = - 64 kJ/mol H_2
7.8 wt.%

G. Barkhordarian et al. (GKSS), J.J. Vajo et al. (HRL), Y.W. Cho et al. (KIST) (2004)

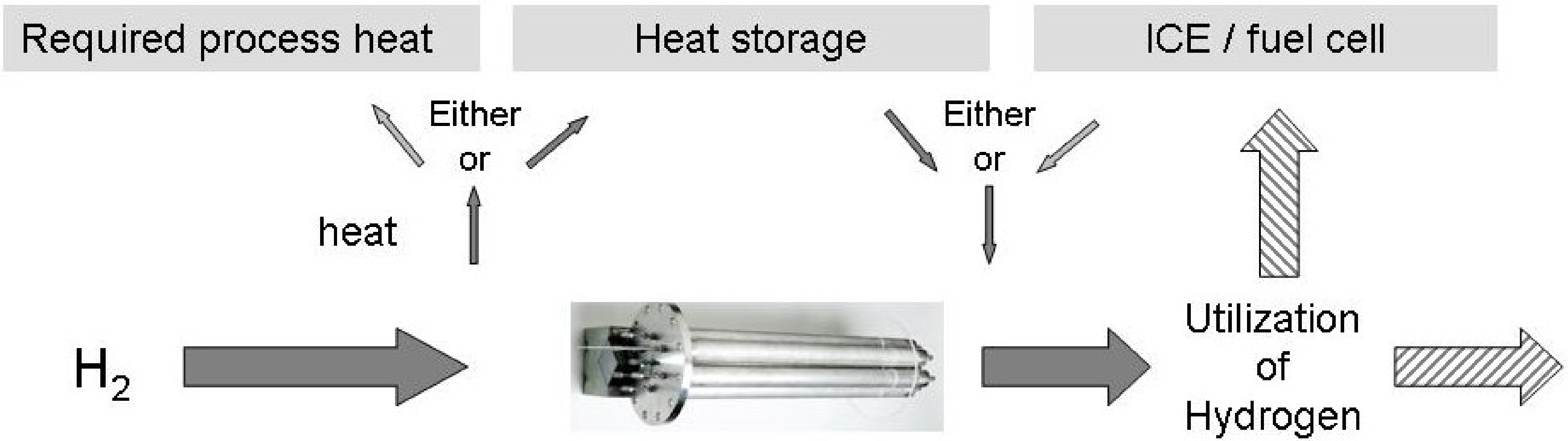
Reactive Hydride Composites

- **High gravimetric storage capacity**
- **Favourable thermodynamic properties**
- **Reversibility under moderate conditions in case of borohydrides**
- **Improvement of Kinetics by additives (nucleation) and sample pre-treatment**

- **Absorption at T ≥ 200 °C**
- **Desorption at T ≥ 240 °C**



Challenges: Examples
Total Energy Efficiency



Heat management in a metal hydride hydrogen storage device.

HYDROGEN IMPLEMENTING AGREEMENT

IEA HIA Tasks on Hydrogen Storage

COMPLETED		
Task 1	Thermochemical Production	1977-1988
Task 2	High Temperature Reactors	1977-1979
Task 3	Assessment of Potential Future Markets	1977-1980
Task 4	Electrolytic Production	1979-1988
Task 5	Solid Oxide Water Electrolysis	1979-1983
Task 6	Photocatalytic Water Electrolysis	1979-1988
Task 7	Storage, Conversion and Safety	1983-1992
Task 8	Technical and Economic Assessment of Hydrogen	1986-1990
Task 9	Hydrogen Production	1988-1993
Task 10	Photoproduction of Hydrogen	1995-1998
Task 11	Integrated Systems	
Task 12	Metal Hydrides for Hydrogen Storage	
Task 13	Design and Optimization	
Task 14	Photoelectrolytic Production	
Task 15	Photobiological Production	
Task 16	Hydrogen from Carbon-Containing Materials	
Task 17	Solid and Liquid State Storage	

Task 17 Operating Agent Gary Sandrock: winner of the inaugural IEA HIA Individual Prize

Current and proposed Tasks

TASK #	TASK NAME	DATES
18	Integrated Systems Evaluation	2004-2009
19	Hydrogen Safety	2004+
20	H2 from Waterphotolysis	2005+
21	BioHydrogen	2005
22	Fundamental &Applied H2 Storage Materials Development	2006-2009
23	Small-Scale Reformers for on-Site H_2 Supply	2006+
24	Wind Energy and Hydrogen Production	2006+
25	High Temperature Production of Hydrogen	2007-2009
26	Advanced Materials for Waterphotolysis with H2	2008+
27	Near-Term Market Routes to H2 via Co-Gasification with Biomass	2008+
In Def	Infrastructure and Mass Storage	

Task 22: Fundamental and Applied Hydrogen Storage Materials Development

December 2006-December 2009

- **3 Targets:**
  - Reversible or regenerative storage media
  - Fundamental & engineering understanding
  - Storage materials for stationary apps

- **20 HIA countries, 53 projects**
  - **Project types**: experimental, engineering, theoretical, safety
  - **Classes of Materials:**
    - Reversible metal hydrides
    - Regenerative hydrogen storage materials
    - Chemical hydrides
    - Nanoporous materials
    - Rechargeable organic liquids and solids

OA: Dr. Bjørn C. Hauback of IET

Task 22: Goals and Targets

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 stationary applications.

Task 22 Project Structure

Projects type:

Experimental

Engineering

Theoretical

Modelling (scientific or engineering)

Safety aspects of hydrogen storage materials

Classes of H-storage media:

Reversible metal hydrides

Regenerative hydrogen storage materials (chemical hydrides)

Nanoporous materials

Rechargeable organic liquids and solids

Collaboration –
a key to solve the storage problem

Nearly every project in T22 with active international collaboration.

Participation and interaction in meetings background for collaboration in regional (EU, Hy-Co, Nordic etc.), IPHE, COST, IAEA, other international and national projects.

Significantly contributed to **collaboration between activities in Europe, America, Asia and Australia.**

Efforts to include IPHE-countries Russia, China, India and Brazil.

Largest international co-operative efforts in this field.

Future of Task 22

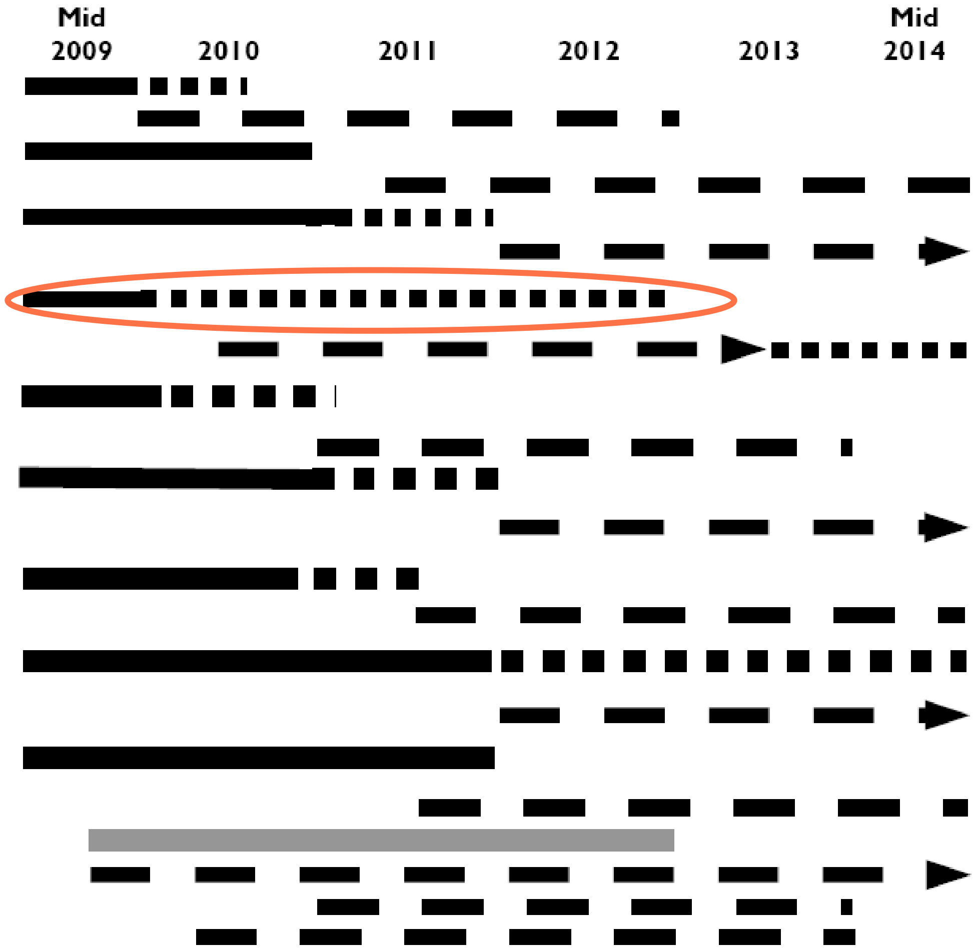
In principal approved for 3 years extension (until end of 2012).

Continue to address development of new materials and fundamental understanding.

- Increased focus on hydrogen storage for stationary applications.
- Specific project(s) addressing engineering issues (plan separate meetings linked to T22 meetings).
- Also include opening for use of hydrides for other energy applications, e.g. metal hydride batteries.

Present and future tasks

Task 18: Integrated Systems Evaluation
Successor: Remote Com Modeling
Task 19: Hydrogen Safety
Successor Safety: Regulatory Framework
Task 21: Biohydrogen
Successor: BioHydrogen
Task 22: Fundamental and Applied Hydrogen Storage Materials
New Task: Applied Storage
Task 23: Small-Scale Reformers for On-Site Hydrogen Supply (SSR)
Successor: Market Studies for SSR
Task 24: Wind Energy & H2 Integration
Successor: Componentry & Low Temp Electrolysis
Task 25: High Temperature H2 Production
Successor: High Temp Electrolysis
Task 26: Advanced Materials for Water photolysis
New Task: PEC Devices
Task 27: Near-Term Market Routes to H2 via Co-Gasification with Biomass
Successor: Gasification & Gas Cleanup
Task 28: In Def. Infrastructure and Mass Storage
New Task: Analysis
New Task: Catalyst Research
New Task: Production Componentry



HYDROGEN IMPLEMENTING AGREEMENT

Theme:

Collaborative R,D&D

Portfolio:

H_2 INFRASTRUCTURE & MASS STORAGE

Large Scale Hydrogen Infrastructure and Mass Storage

Task in definition

International Energy Agency Hydrogen Implementing Agreement . . .

www.ieahia.org

. . . A premier global resource for technical expertise in Hydrogen RD&D

Thank you for your attention!