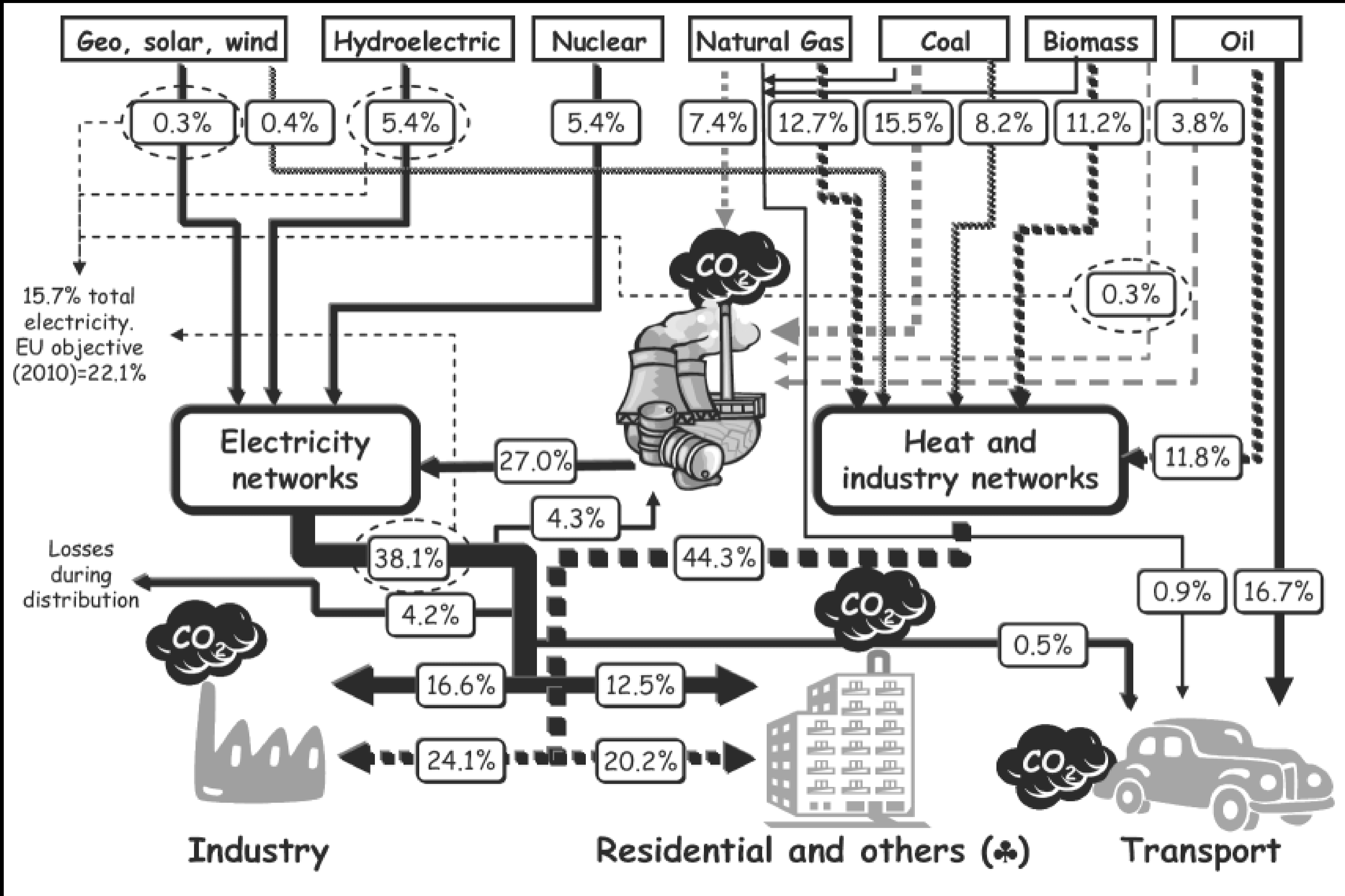
Hydrogen?

Energy Materials: Meeting the Challenge

10th October 2008

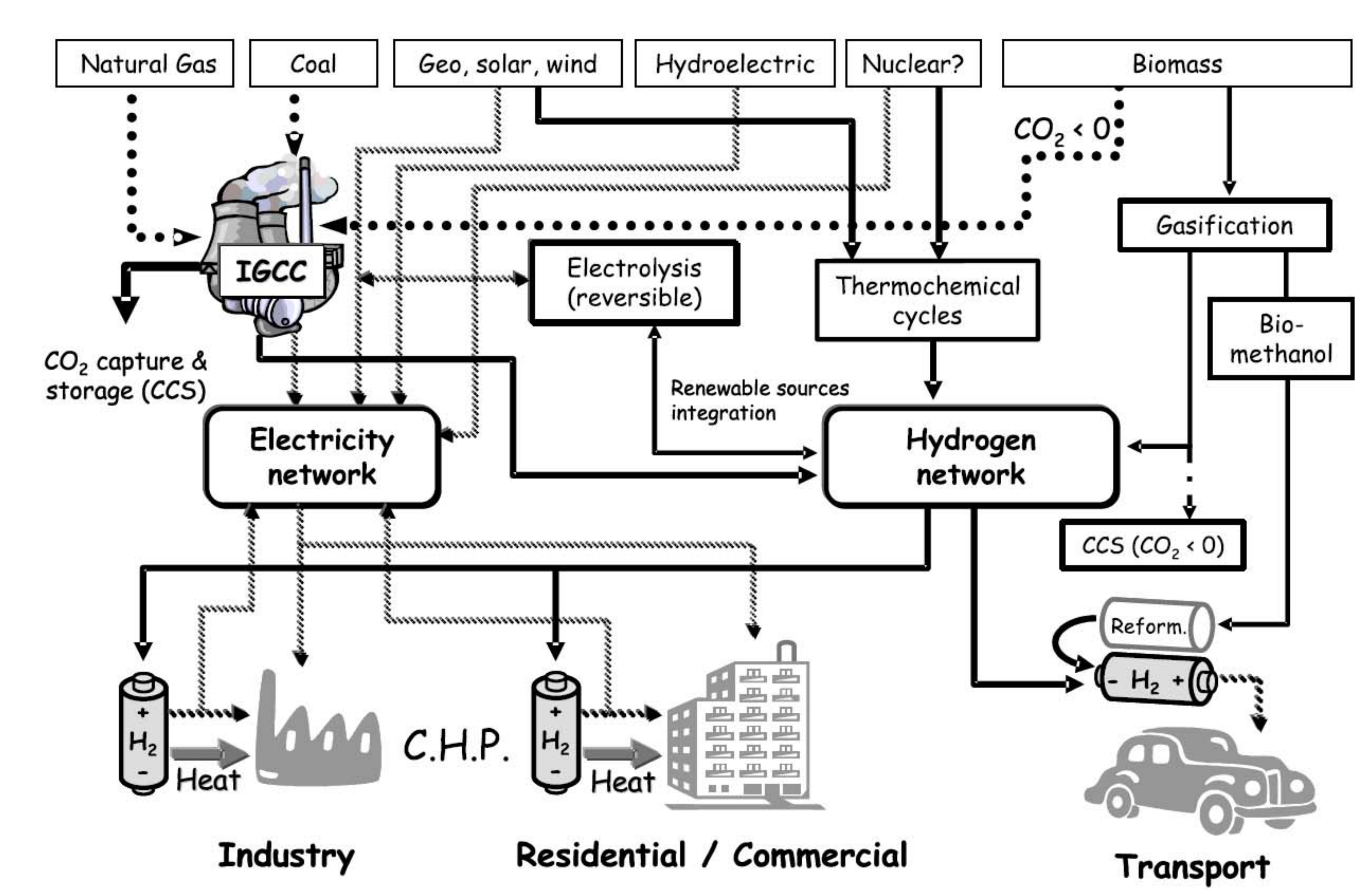
Professor Peter P. Edwards
University of Oxford

The Carbon Economy



G. Marbán and T. Valdés-Solís, International Journal of Hydrogen Energy, 2007, 32, 1625-1637

Hydrogen Economy



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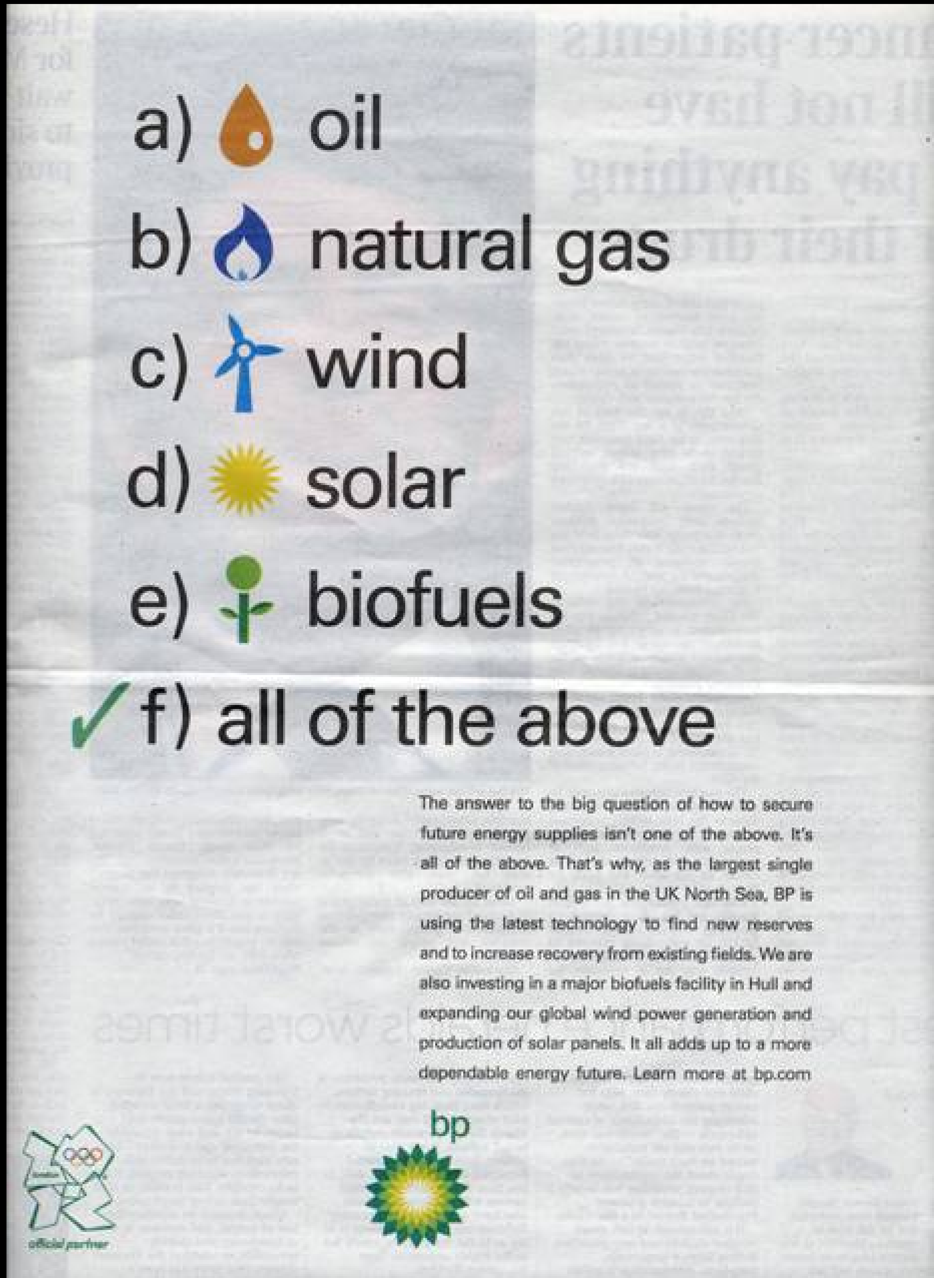
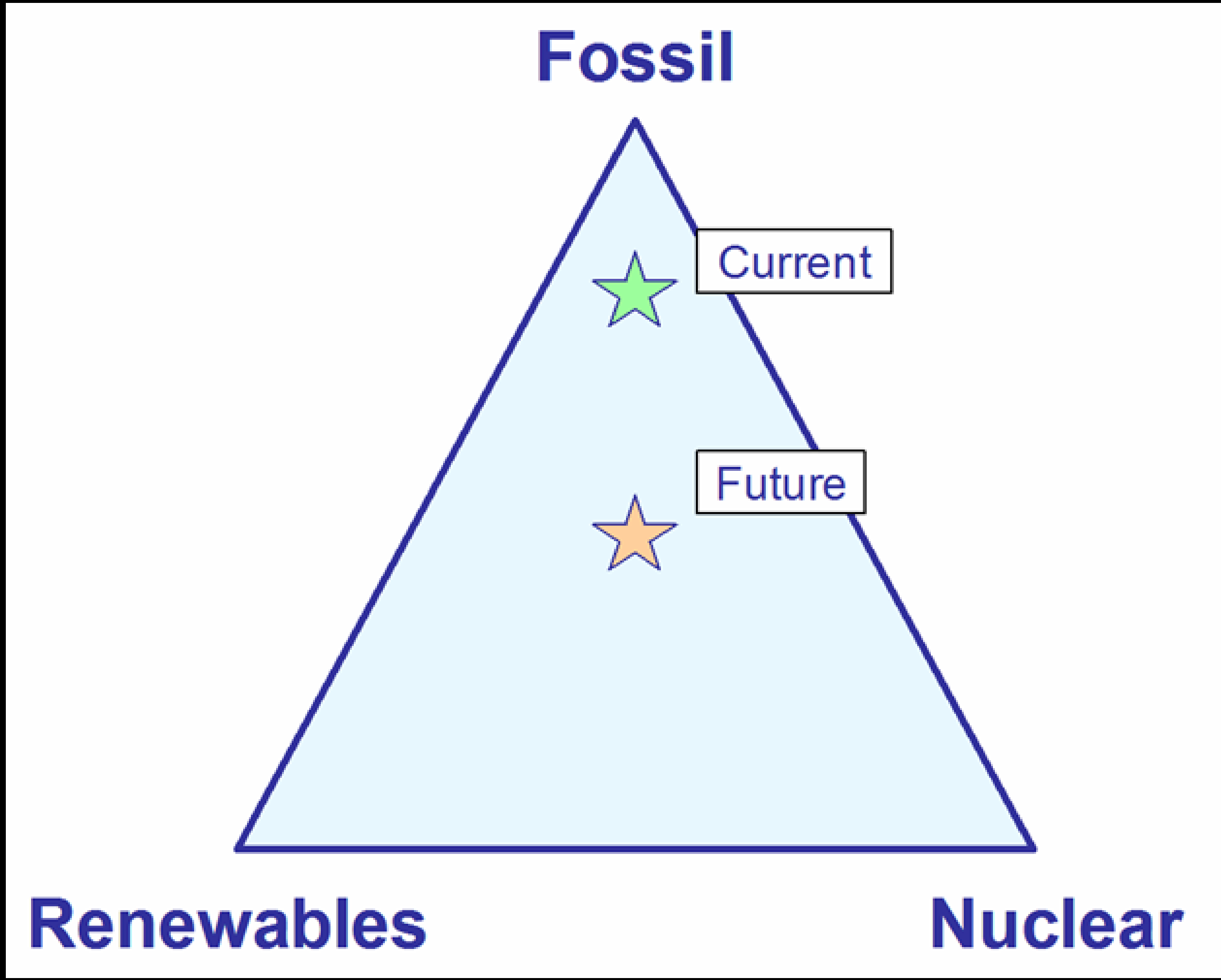
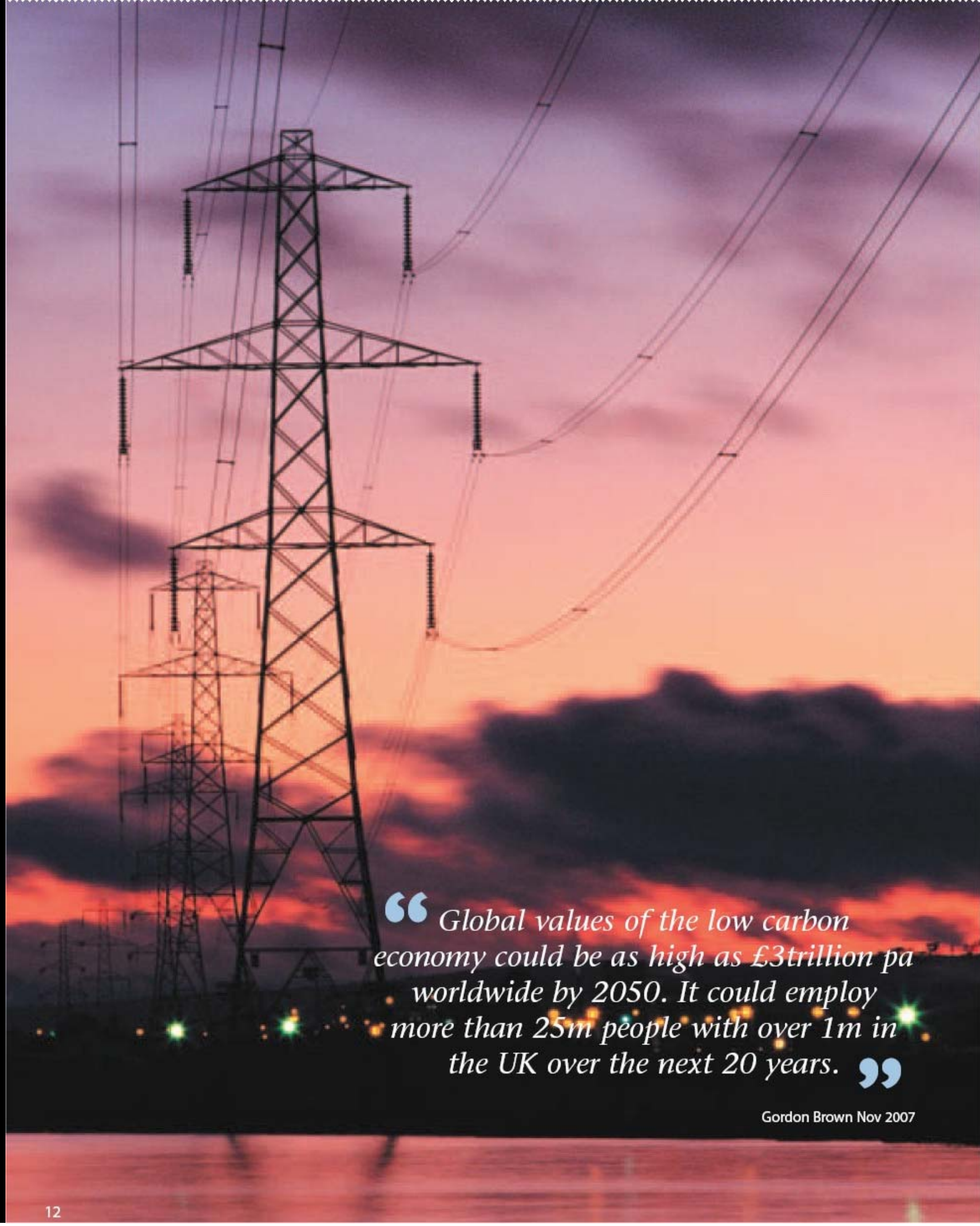


The Times, **September 24th 2008**

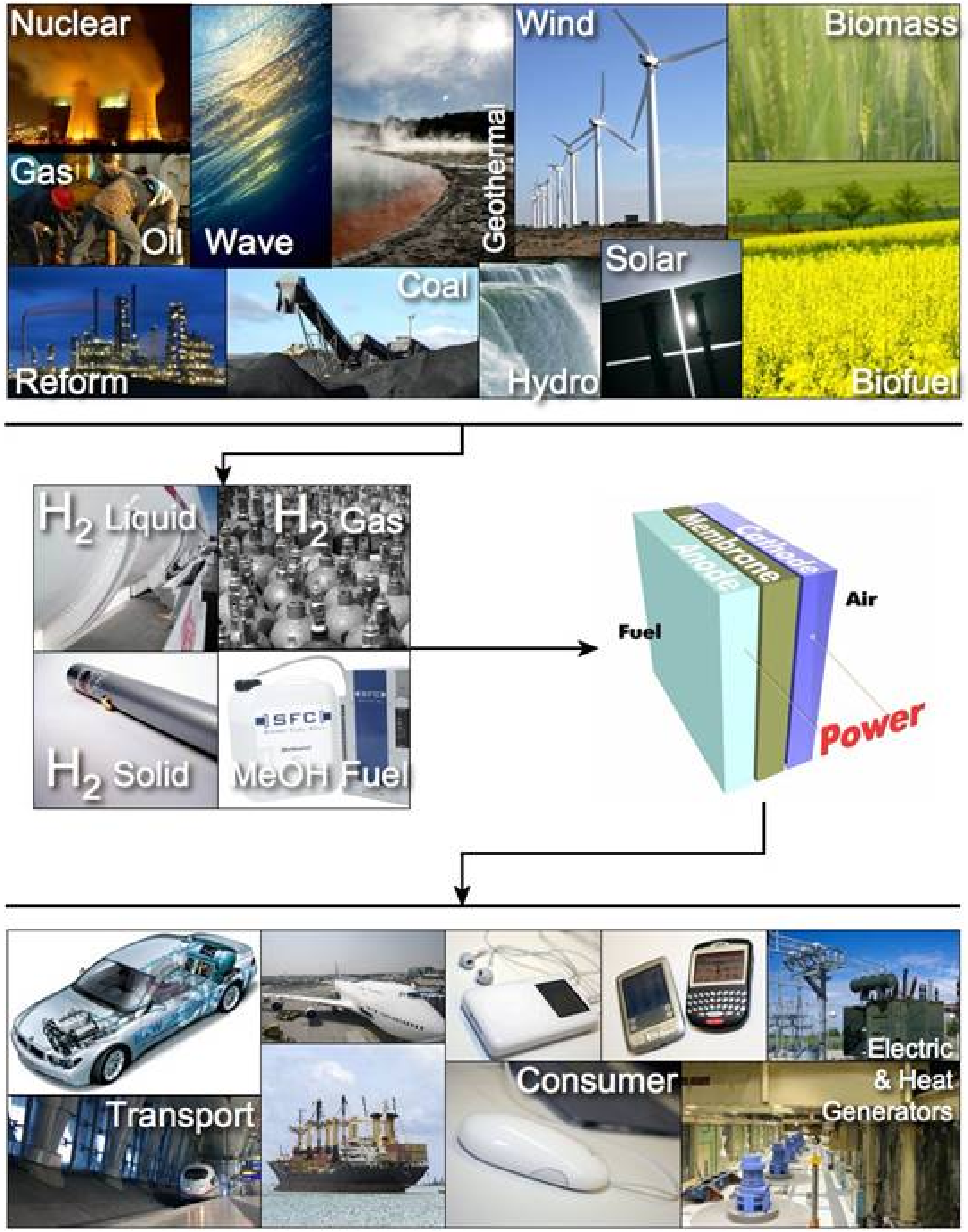
UK primary energy supply structure and the present and future position of UK energy mix





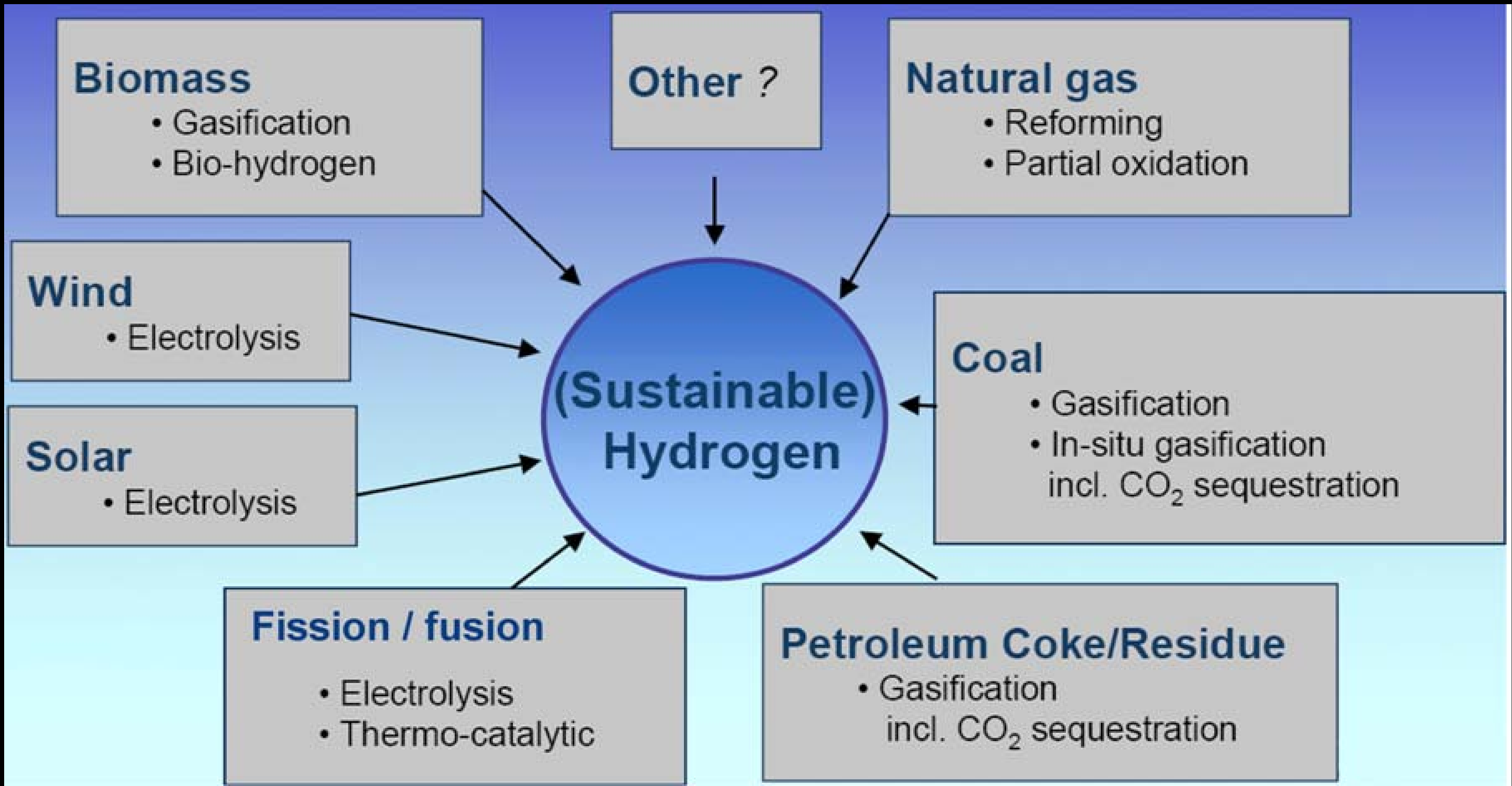
"Global values of the low carbon economy could be as high as £3trillion pa worldwide by 2050. It could employ more than 25m people with over 1m in the UK over the next 20 years."

Gordon Brown Nov 2007


Nuclear
Gas
Oil
Wave
Geothermal
Wind
Biomass
Solar
Coal
Reform
Hydro
Biofuel
H_2 Liquid
H_2 Gas
H_2 Solid
MeOH Fuel
Cathode
Membrane
Anode
Air
Fuel
Power
Transport
Consumer
Electric
& Heat
Generators

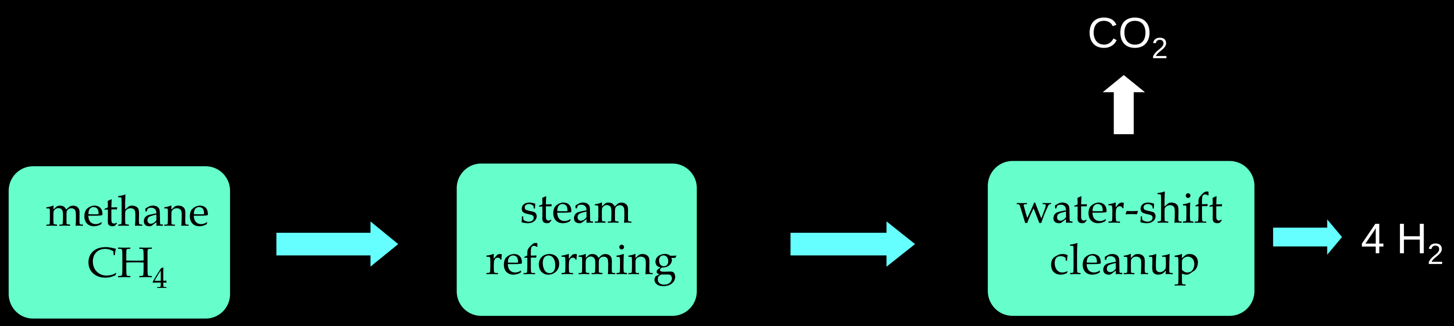
The Challenges and Opportunities of Hydrogen

Hydrogen Production



Sustainable Hydrogen, a European Perspective, Prof. Dr. J. Schoonman
GCEP Hydrogen Conference, Stanford University, April 14-15, 2003

Hydrogen Production Challenges:
Hydrogen from Fossil Fuels



$CH_4 + H_2O \rightarrow CO + 3H_2$

$\Delta G = + 150$ kJ

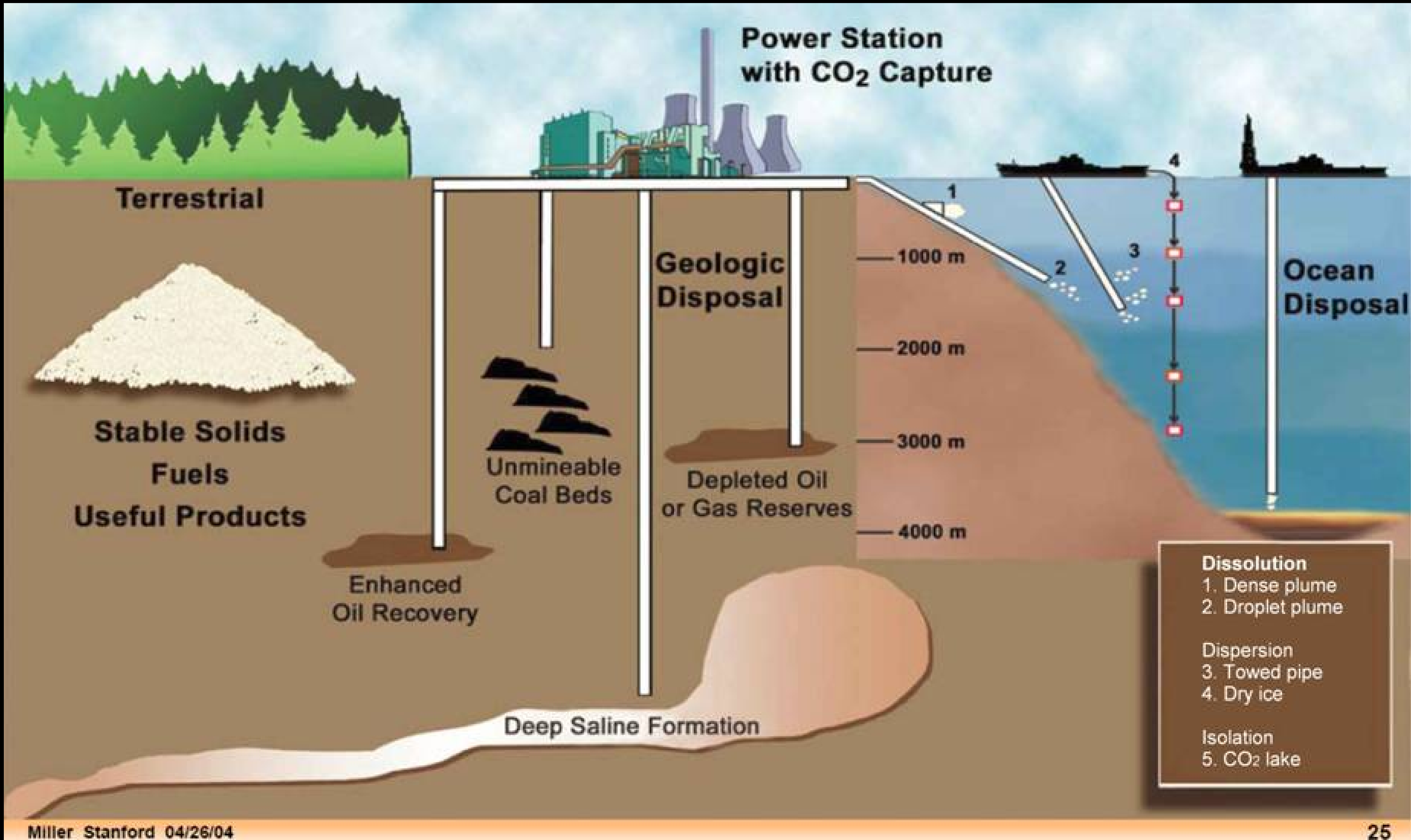
$CO + H_2O \rightarrow CO_2 + H_2$

$\Delta G = - 19$ kJ

technology in place

marginal effect on energy challenges

CO_2 Capture and Storage



THE ROYAL SOCIETY

Ocean acidification due to increasing atmospheric carbon dioxide

Action needs to be taken now to reduce global emissions of CO_2 to the atmosphere to avoid the risk of large and irreversible damage to the oceans. We recommend that all possible approaches be considered to prevent CO_2 reaching the atmosphere. No option that can make a significant contribution should be dismissed.

Policy document 12/05

June 2005

ISBN 0 85403 617 2

This report can be found at www.royalsoc.ac.uk

excellence in science

Carbon Dioxide Elaboration : The Oxford Energy Cycle

Renewable Energy (all Known Sources)

↓

Electricity - then electrolysis of water

↓

Hydrogen

Sequestered

$CO_2 + H_2 \rightarrow CO + H_2O$

$2H_2 + CO \rightarrow (CH_2)_n + H_2O$

Hydrocarbons

Store energy as hydrocarbons

Transport energy as hydrocarbons

Use hydrocarbons as liquid fuels

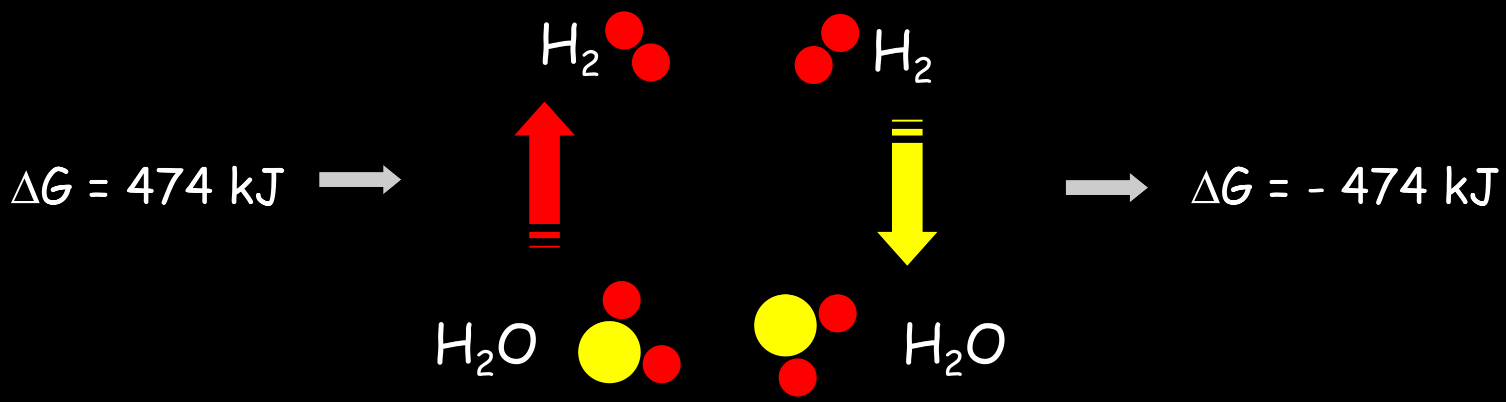
Hydrocarbons + air $\rightarrow CO_2$ + water

NET production of carbon dioxide is ZERO

M. L. H. G and P. P. E

Hydrogen Production Challenges:
Hydrogen from H_2O Splitting

the H_2/water cycle

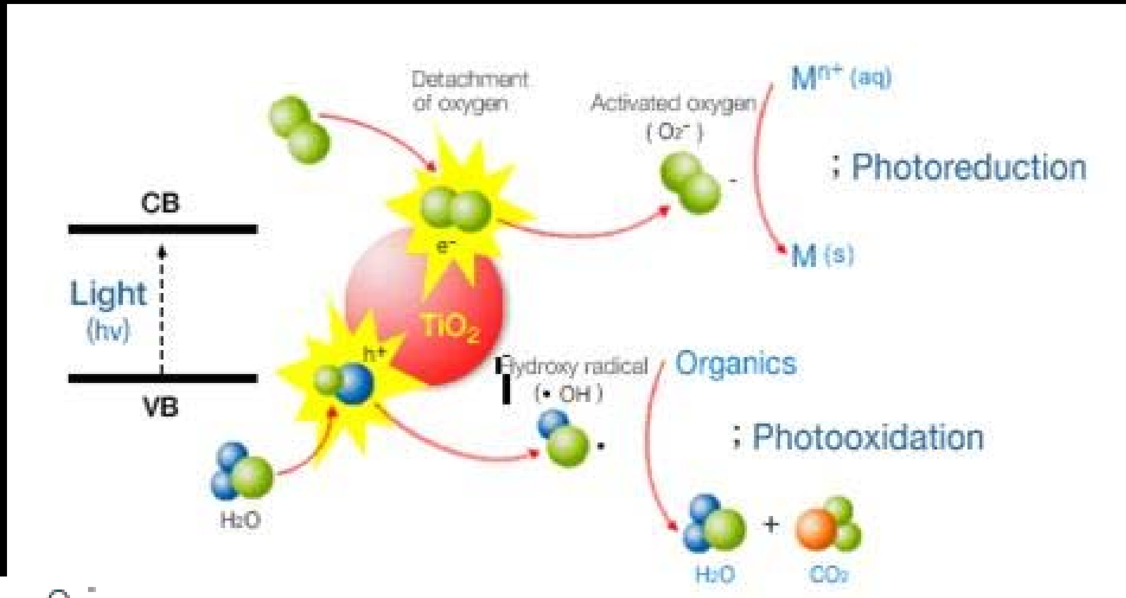


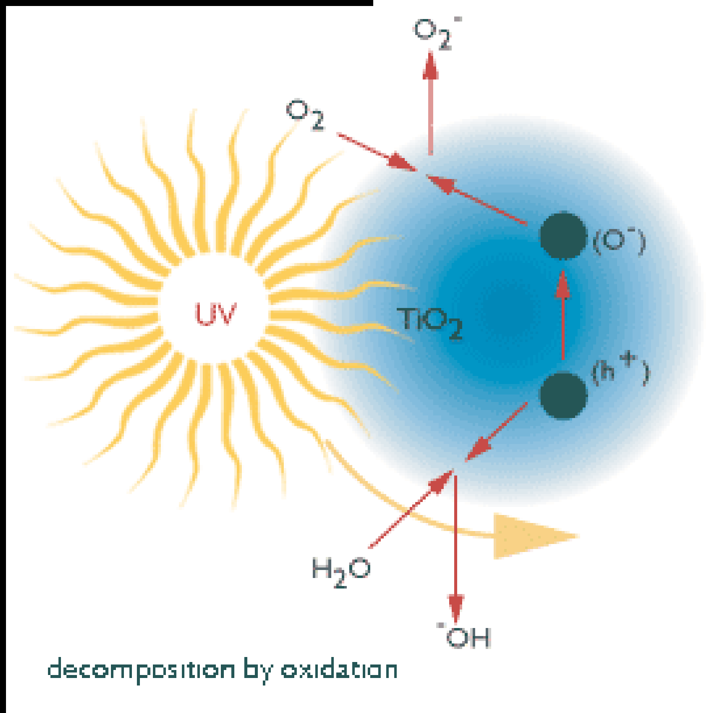
energy sources
non-fossil electricity
solar, hydro, wind, nuclear
solar/nuclear heat
fossil electricity/heat

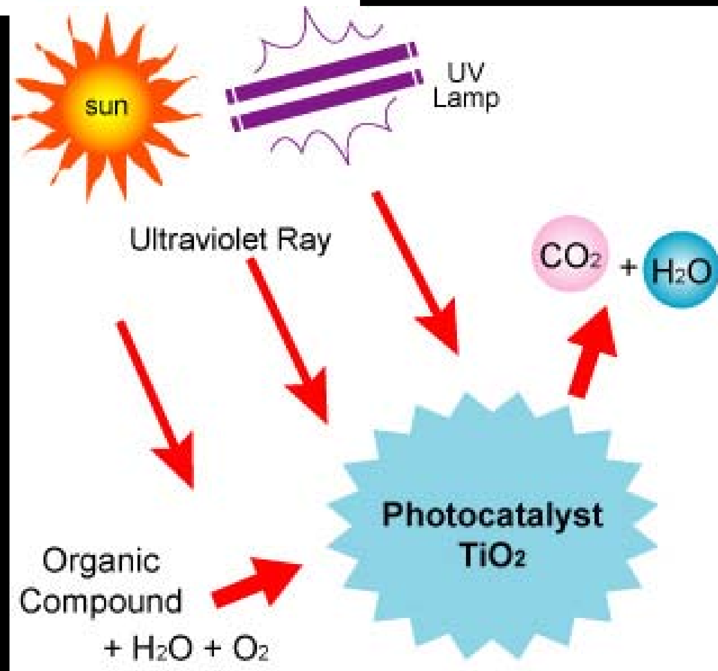
H_2 liberation
electrolysis
photo-electrolysis
dissociation
thermochemical cycle

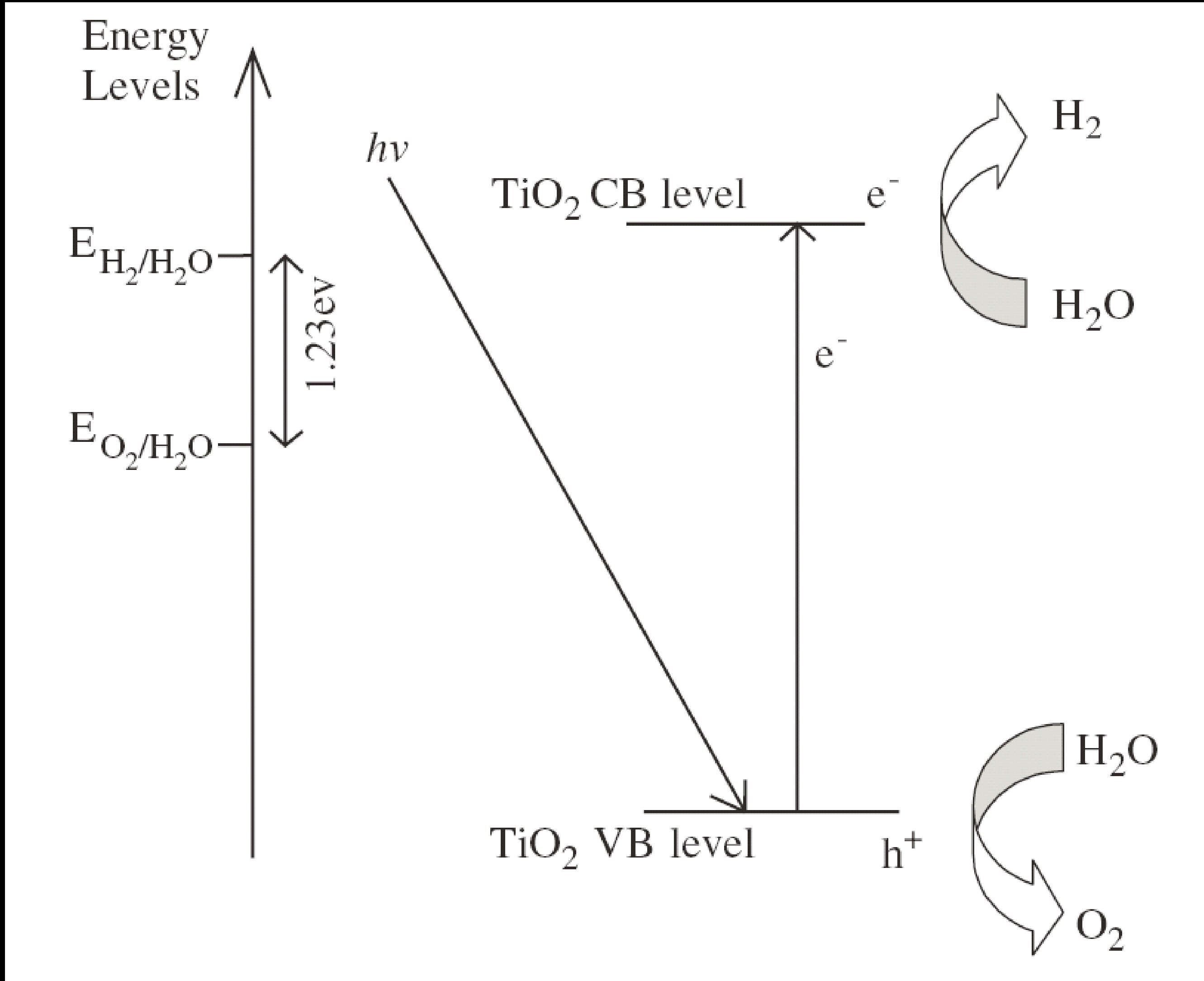
H_2 conversion
fuel cell: electricity/heat
heat engine
combustion

Water Splitting





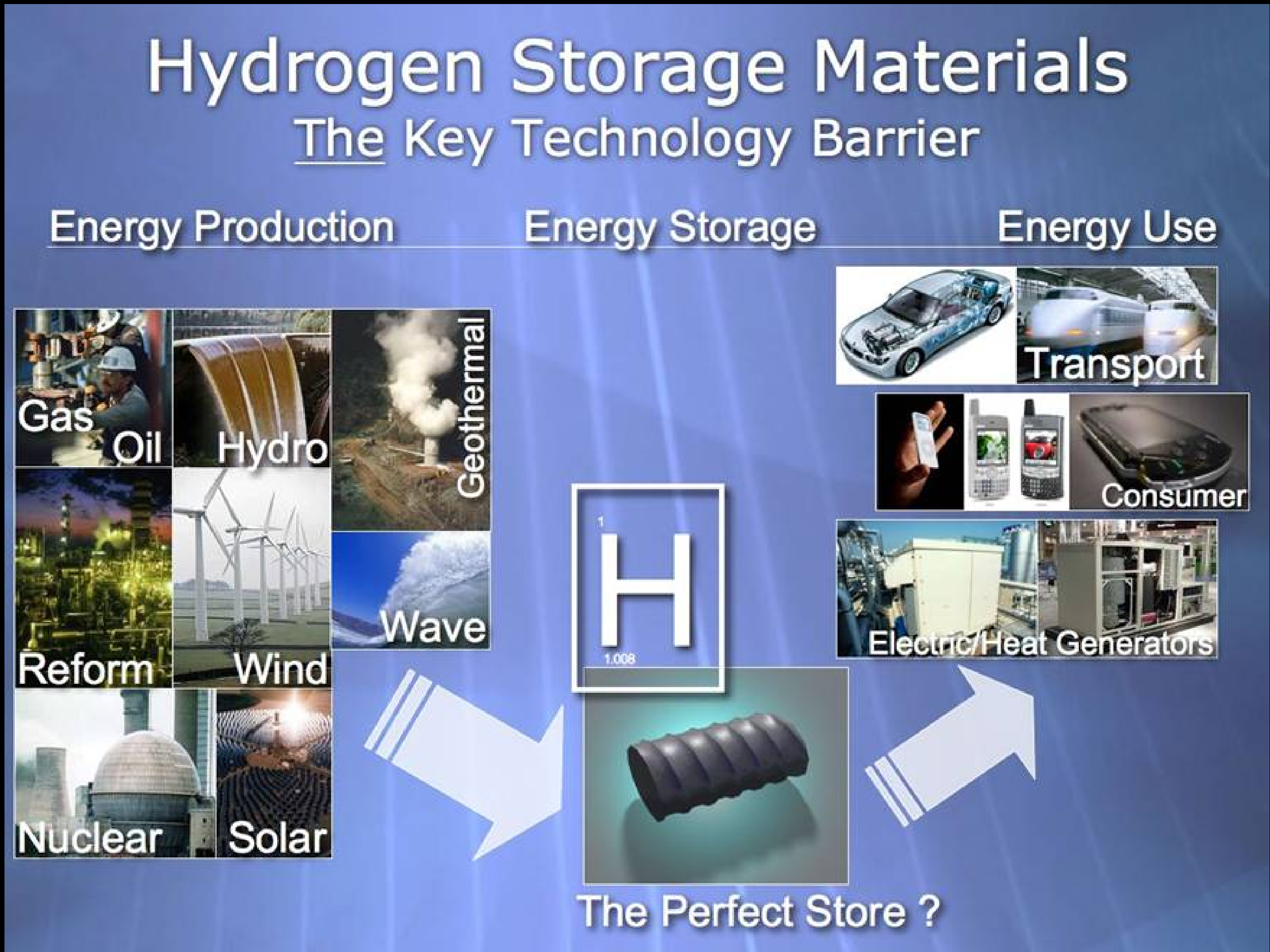




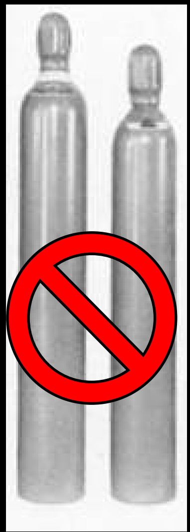
Energy
Levels
hv
TiO_2 CB level
e^-
H_2
H_2O
E_{H_2/H_2O}
1.23ev
e^-
E_{O_2/H_2O}
H_2O
TiO_2 VB level
h^+
O_2

The Challenges and Opportunities of Hydrogen

Hydrogen Storage



Hydrogen Storage: Gas and Liquid



gaseous storage

5000 psi = 350 bar

10000 psi = 700 bar
fiber reinforced
composite containers

liquid storage

standard in stationary applications
portable cryogenics for auto
30-40% energy lost to liquifaction

within technological reach

Hydrogen Storage

Toyota Fuel Cell Hybrid Vehicle

70 Mpa (700 atmosphere) hydrogen tank

Range 760 kilometers (472 miles), Cold Start -30° Celsius

Hydrogen to fuel this car for 400km; stored as compressed gas, cryogenic liquid and solid state stores

L. Schlapbach and A. Züttel,
Nature **414** (2001), p. 353

Hydrogen and Fuel Cell Expo 2006

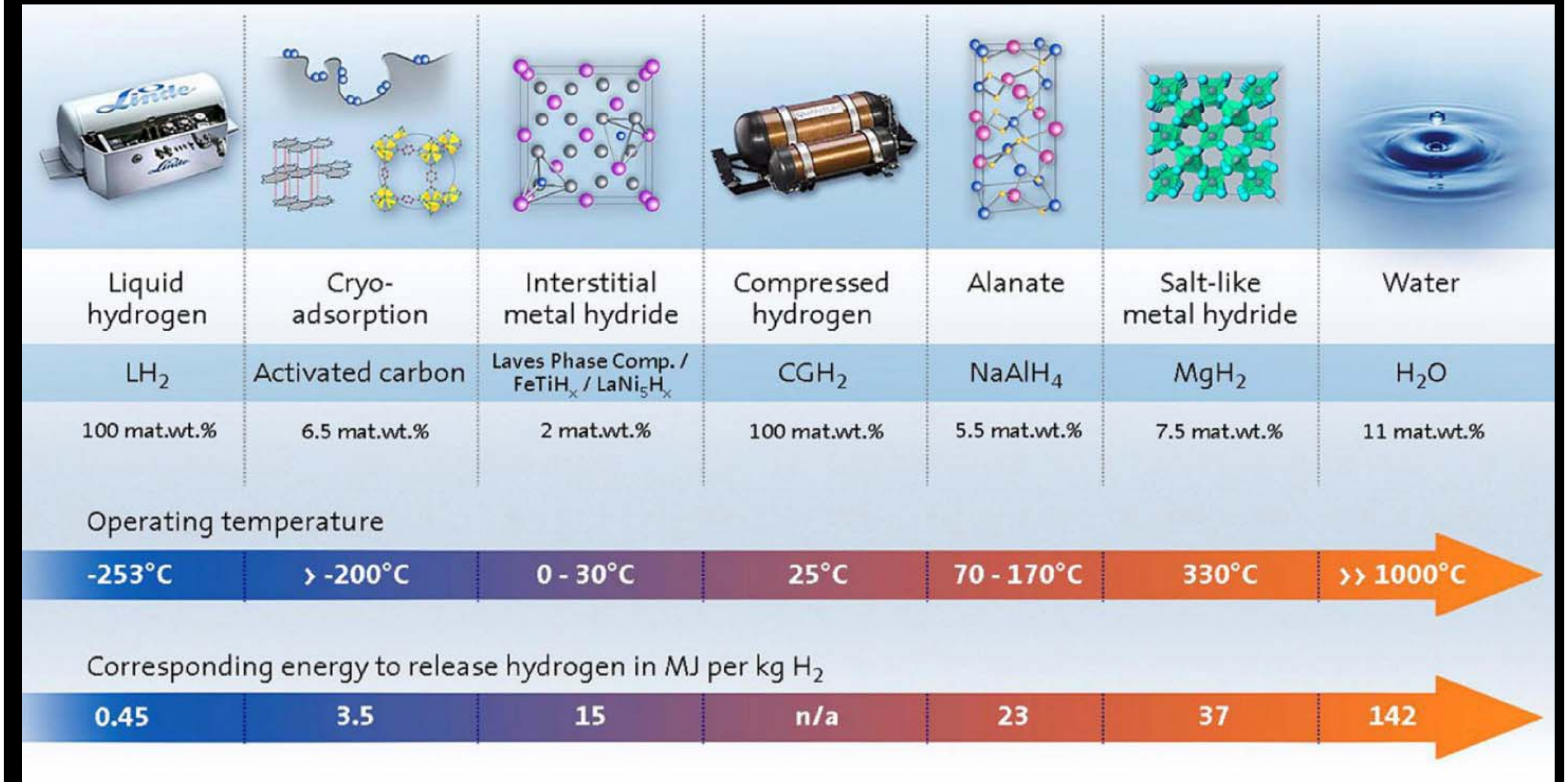
400 Exhibitors, 23,039 Professional Visitors

"There exists the necessity for an epoch-making advance in new materials for hydrogen storage…. This is the hardest challenge"

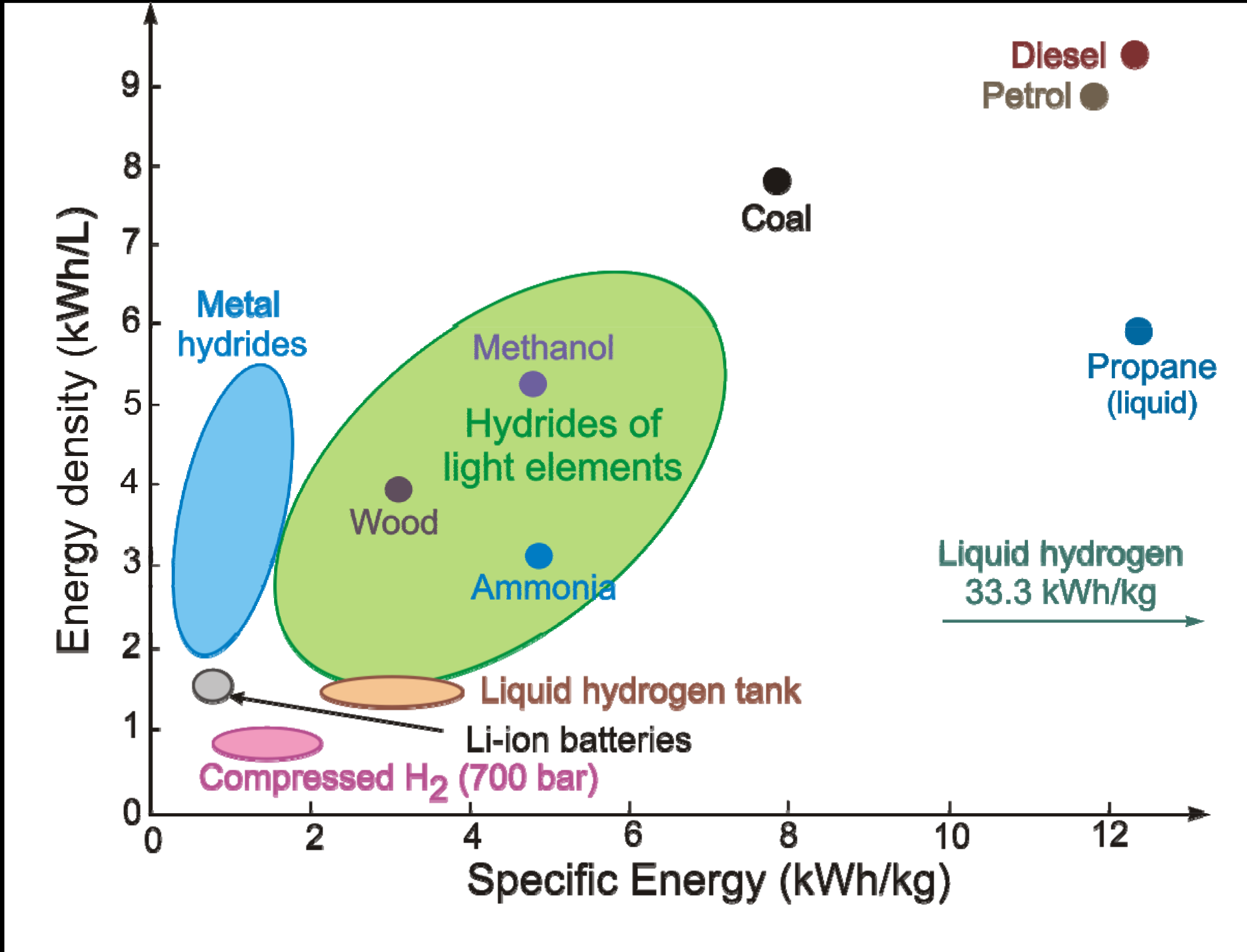
Masatami Takimoto

Executive Vice President, Toyota Motor Corporation

Hydrogen Storage

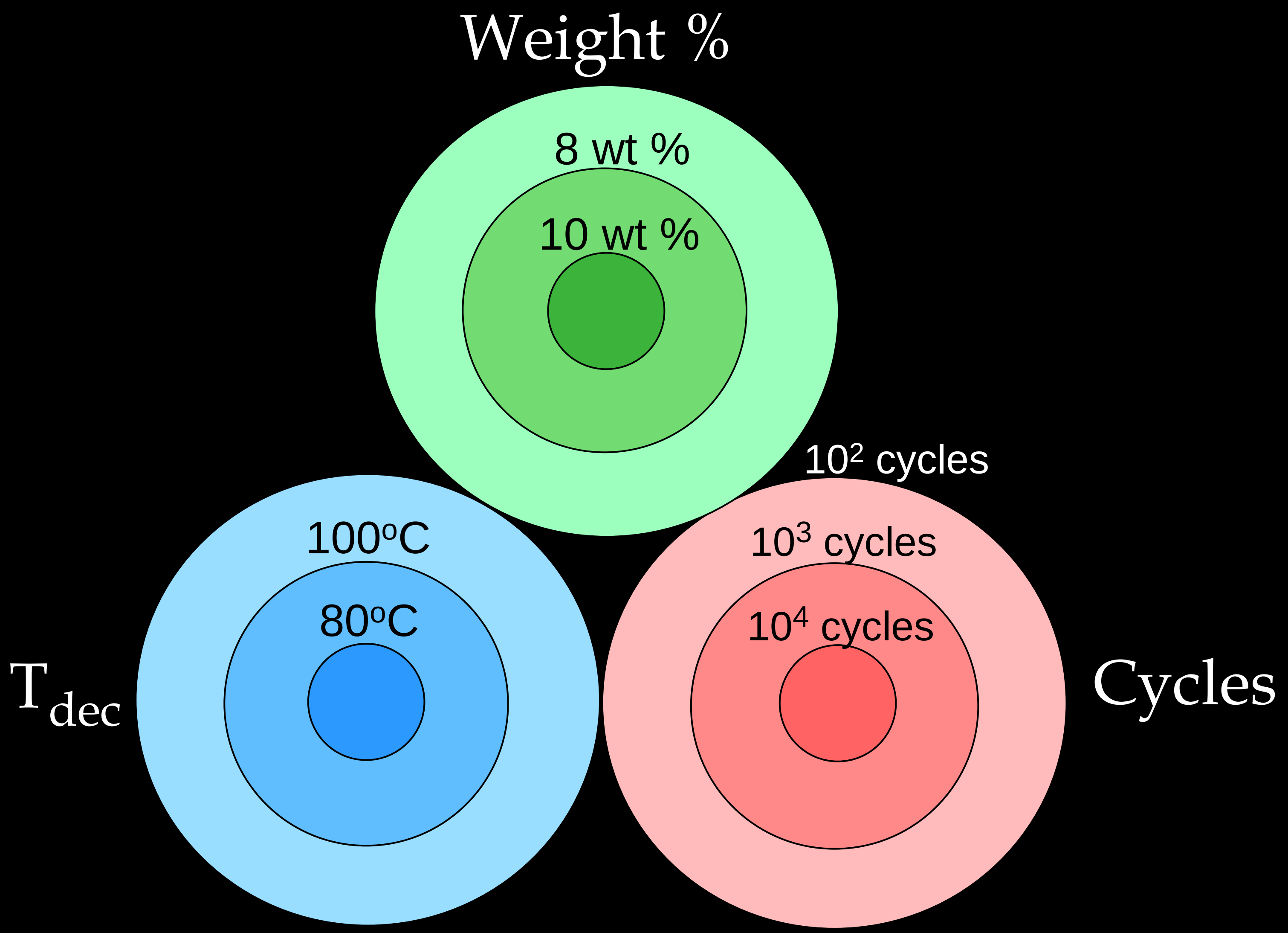


R.Helmolt, U.Eberle (General Motors), *J. Power Sources*, 2007, 165, p.833

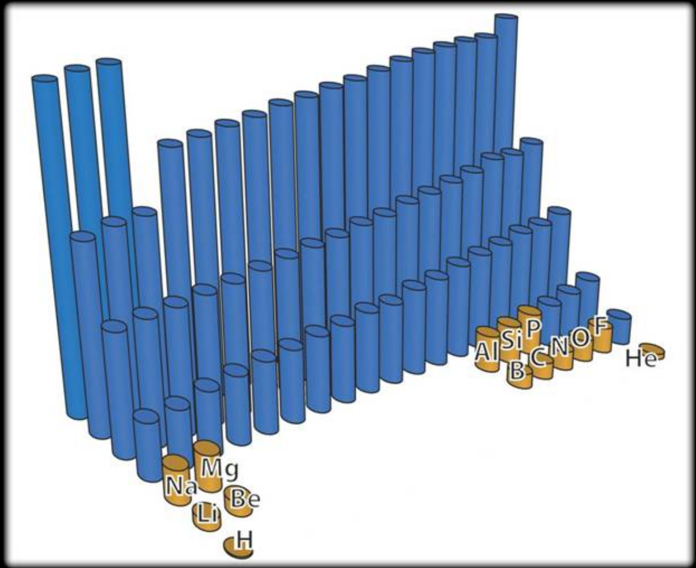


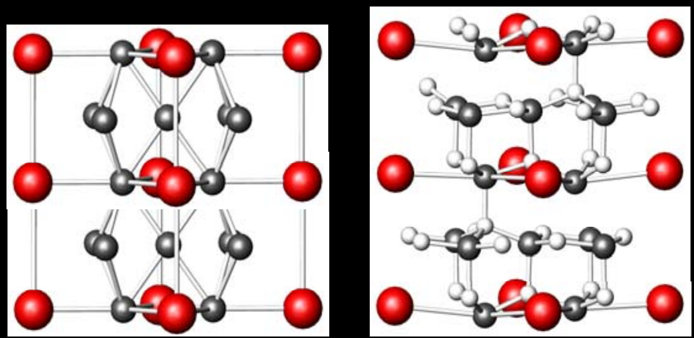
Diesel
Petrol
Coal
Metal hydrides
Methanol
Hydrides of light elements
Wood
Ammonia
Propane (liquid)
Liquid hydrogen 33.3 kWh/kg
Liquid hydrogen tank
Li-ion batteries
Compressed H_2 (700 bar)
Energy density (kWh/L)
Specific Energy (kWh/kg)
0
1
2
3
4
5
6
7
8
9
0
2
4
6
8
10
12

Performance Criteria



Hydrogen Storage

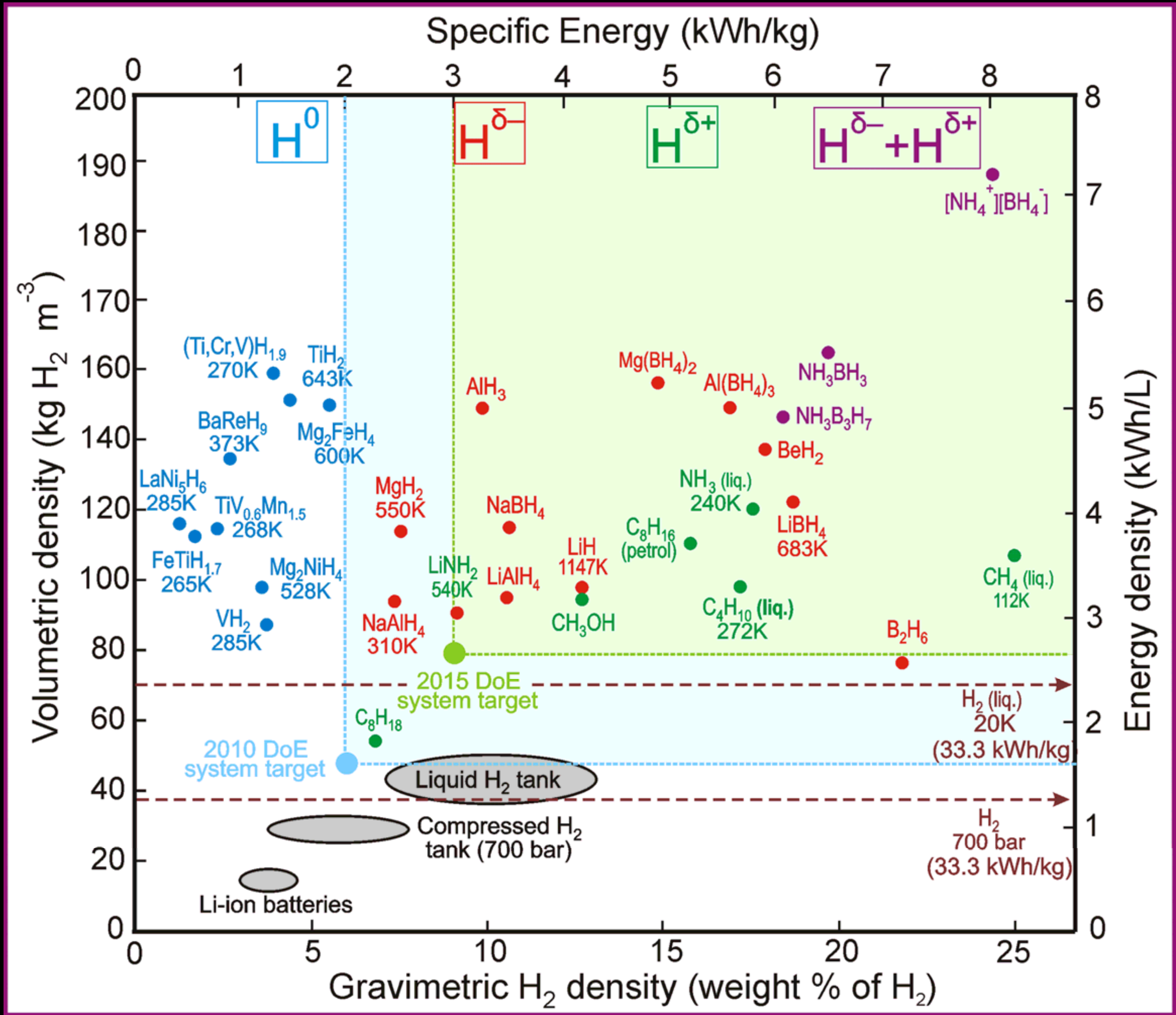


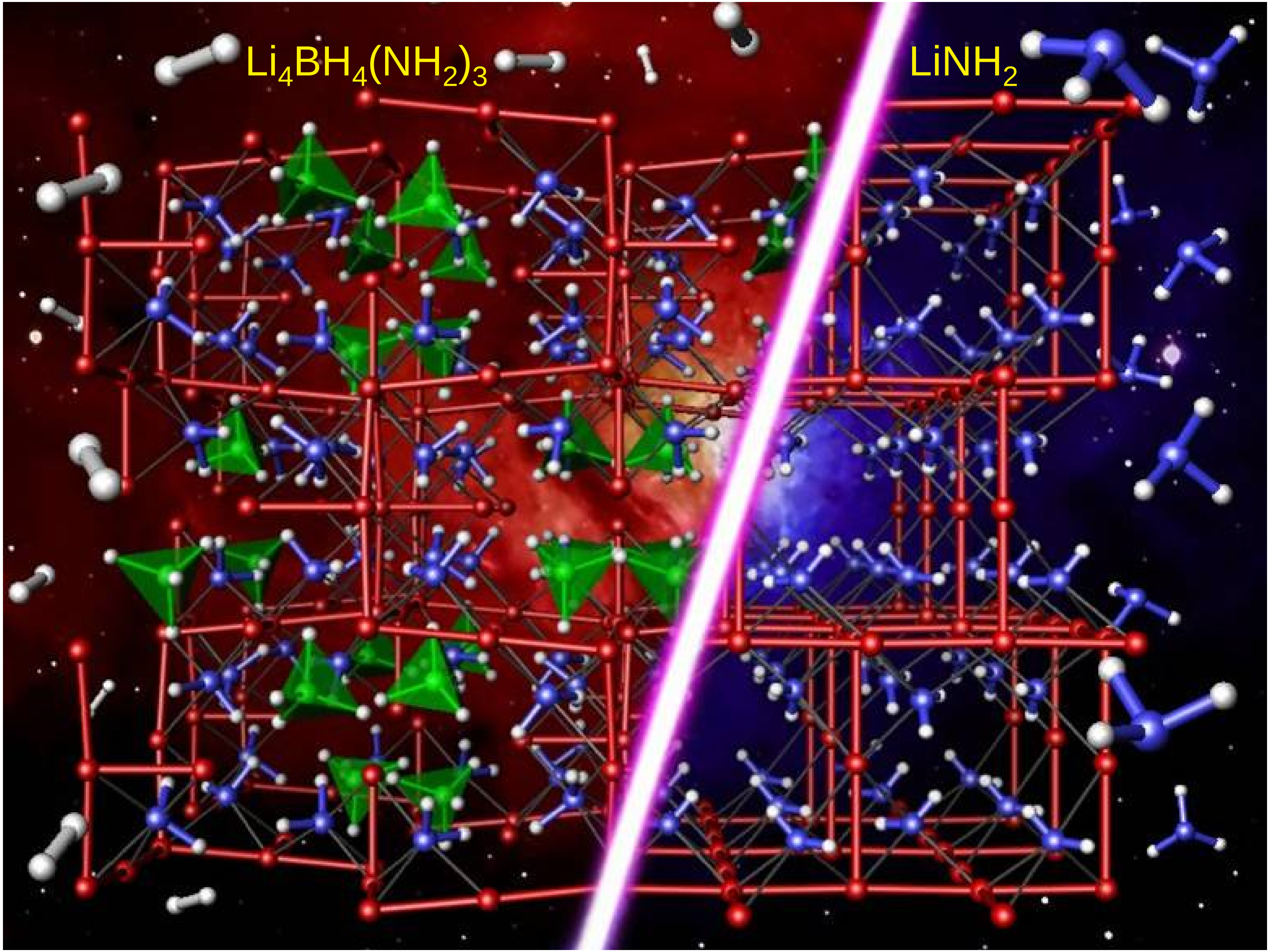


$LaNi_5 \leftrightarrow LaNi_5H_7$

- High gravimetric density
  - *The challenge of the light periodic table*
- Low decomposition temperature
  - *Thermodynamic control*
- Reversibility
  - *Electronic and ionic mobility*

Controlling Gravimetric and Volumetric Densities




$Li_4BH_4(NH_2)_3$
$LiNH_2$

nature materials

High-capacity hydrogen storage in lithium and sodium amidoboranes

ZHITAO XIONG[1], CHAW KEONG YONG[1], GUOTAO WU[1], PING CHEN[1,2]*, WENDY SHAW[3], ABHI KARKAMKAR[3], THOMAS AUTREY[3], MARTIN OWEN JONES[4], SIMON R. JOHNSON[4], PETER P. EDWARDS[4] AND WILLIAM I. F. DAVID[5]

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[5]ISIS Facility, Rutherford Appleton Laboratory, Chilton OX11 0QX, UK
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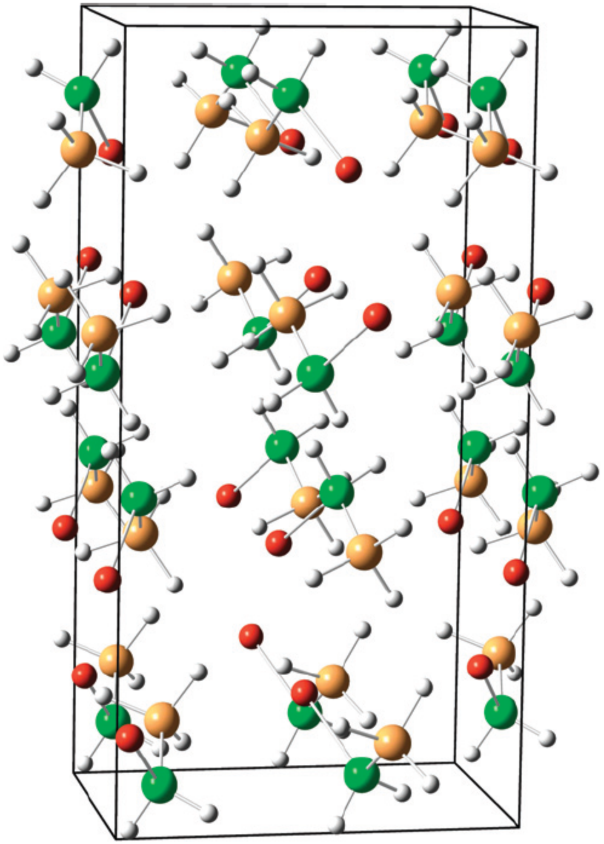


The Perfect Store for Hydrogen
Not Yet Discovered

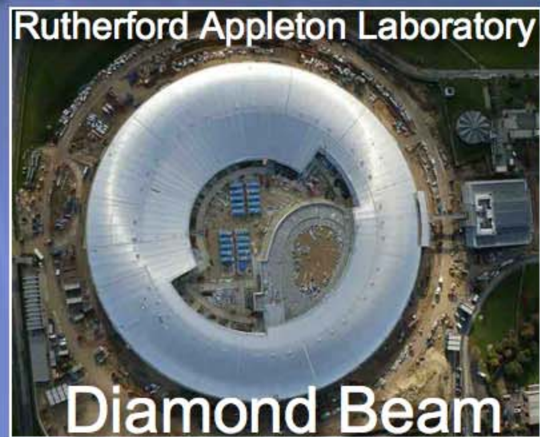
Only a few elements can make suitable lightweight storage materials

Li	B	C	N	Na	Mg	Al	P	Si

Make tens of thousands of new materials from combinations of these elements

Rapidly identify and test these new materials

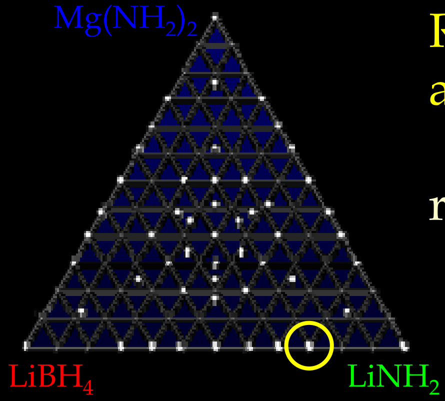
Together will aim to discover new materials with > 6wt% hydrogen storage



Rapid throughput materials discovery and characterisation

robotic synthesis ~30mg quantities

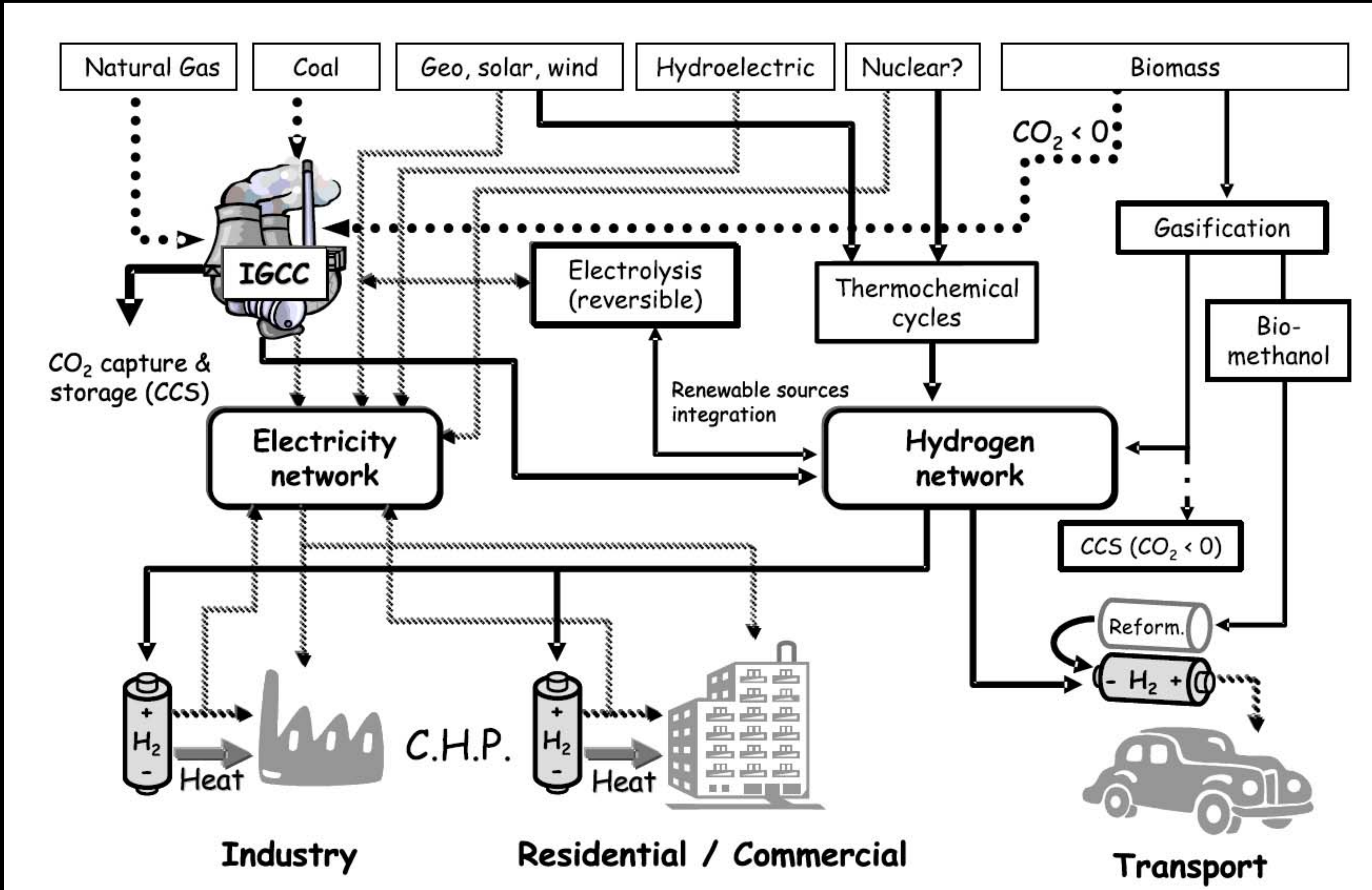
R79 – rapid throughput



Science & Technology Facilities Council

UNIVERSITY OF OXFORD

Hydrogen Economy



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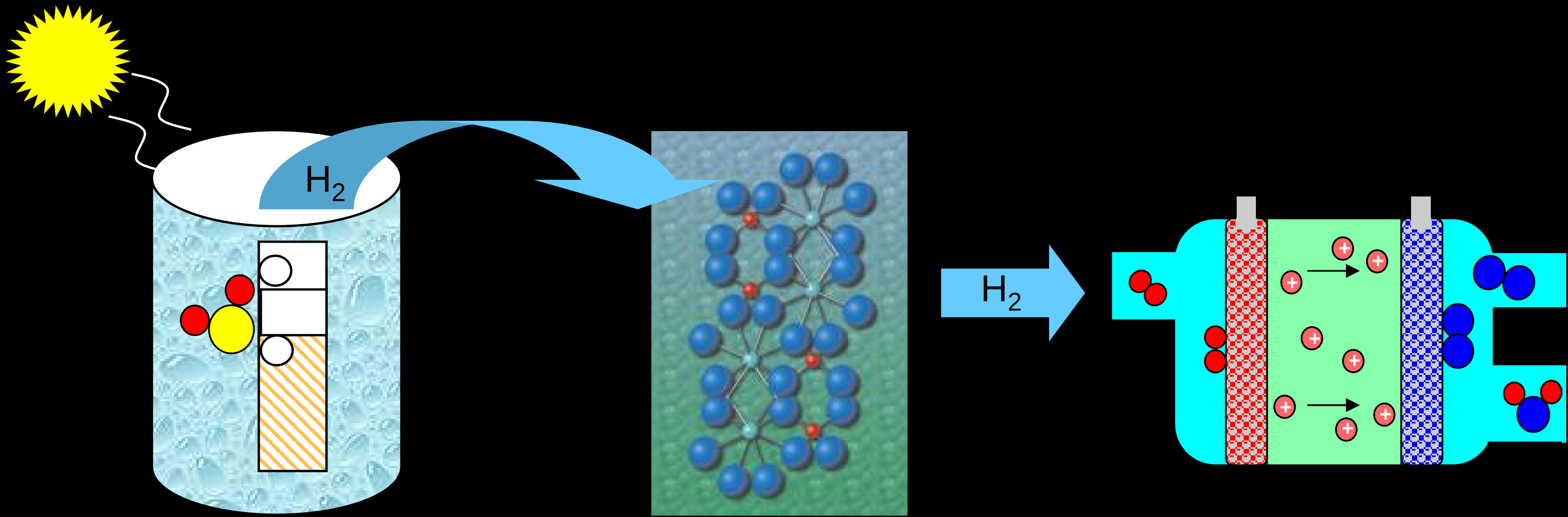
Outlook: The Step-Change Hydrogen Economy



Production
by splitting water renewably

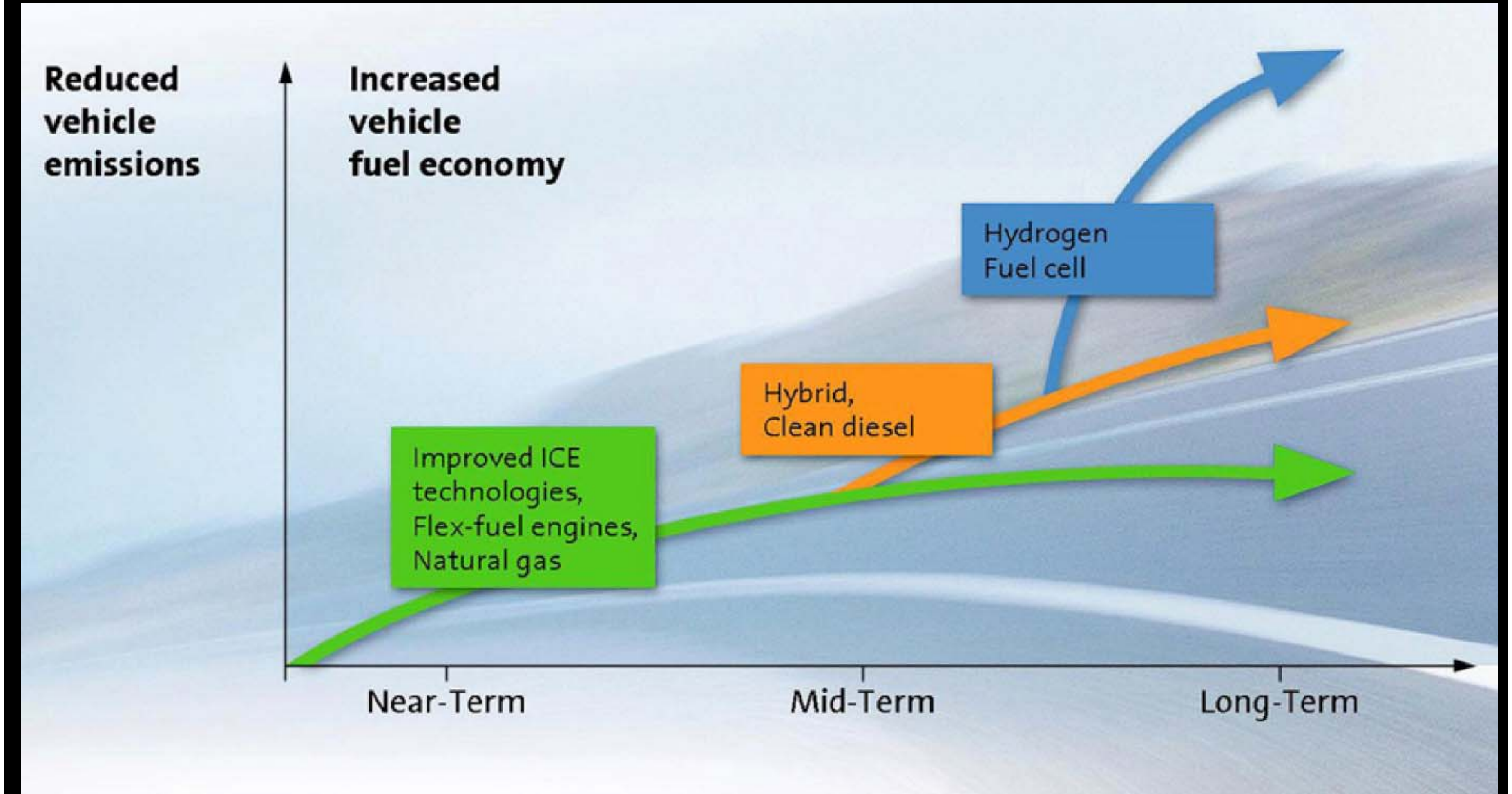
Storage
in solid materials

Use
in fuel cells

addresses the energy challenges
supply, security, pollution, climate

science within reach
breakthrough research discoveries
catalysis, materials, nanoscale science and engineering, bio-mimetics

Transition from today's technologies to future hydrogen-powered fuel cell vehicles



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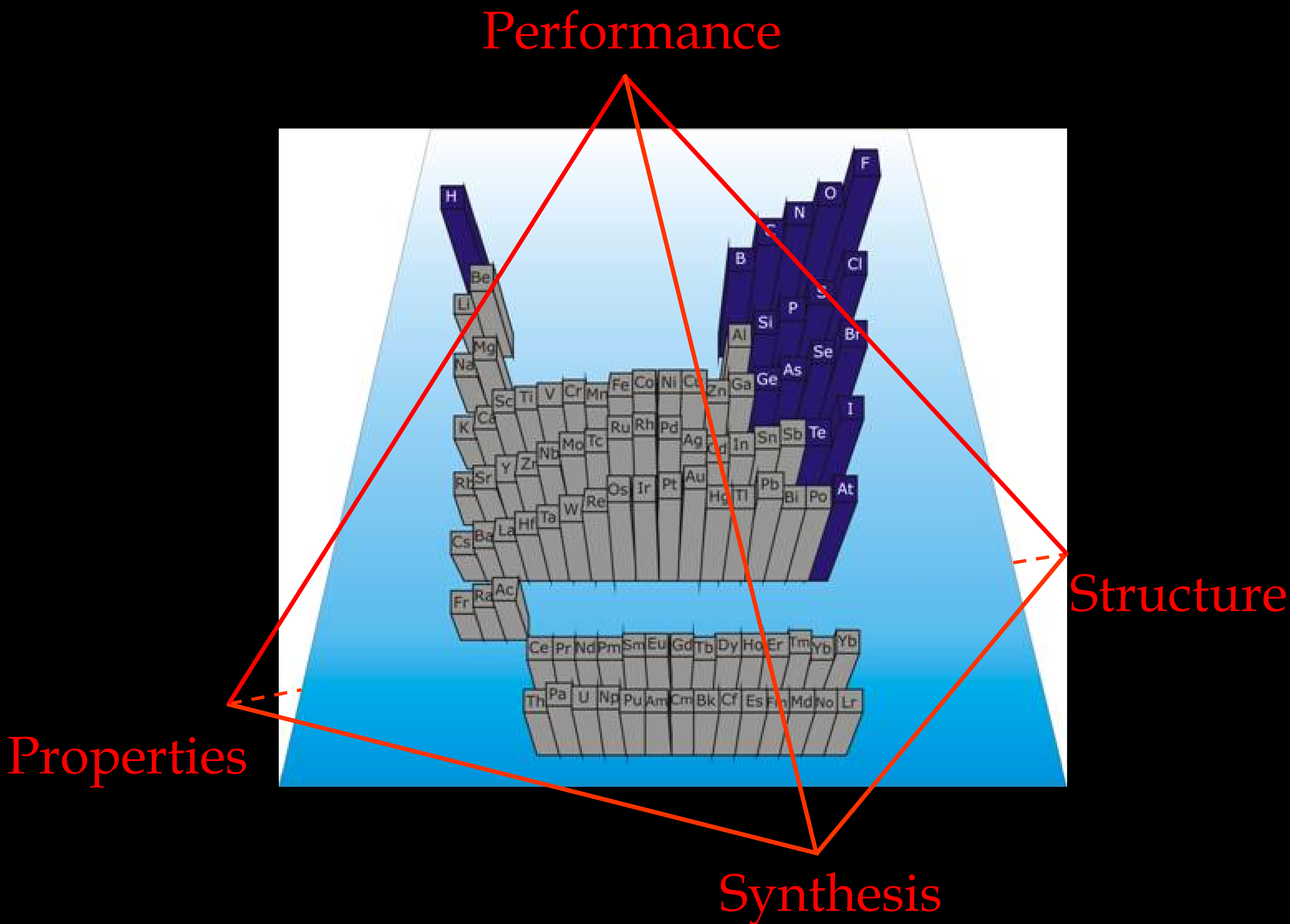

Acknowledgements

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Martin Owen Jones	*Oxford*
Vladimir Kuznetsov	*Oxford*