Hydrogen and Magnets Partners in the Drive to Sustainability

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Understanding the Low Carbon Economy
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"Why do we need renewable / sustainable energy?"

Drivers for change:

1) Climate change ("Global Warming")

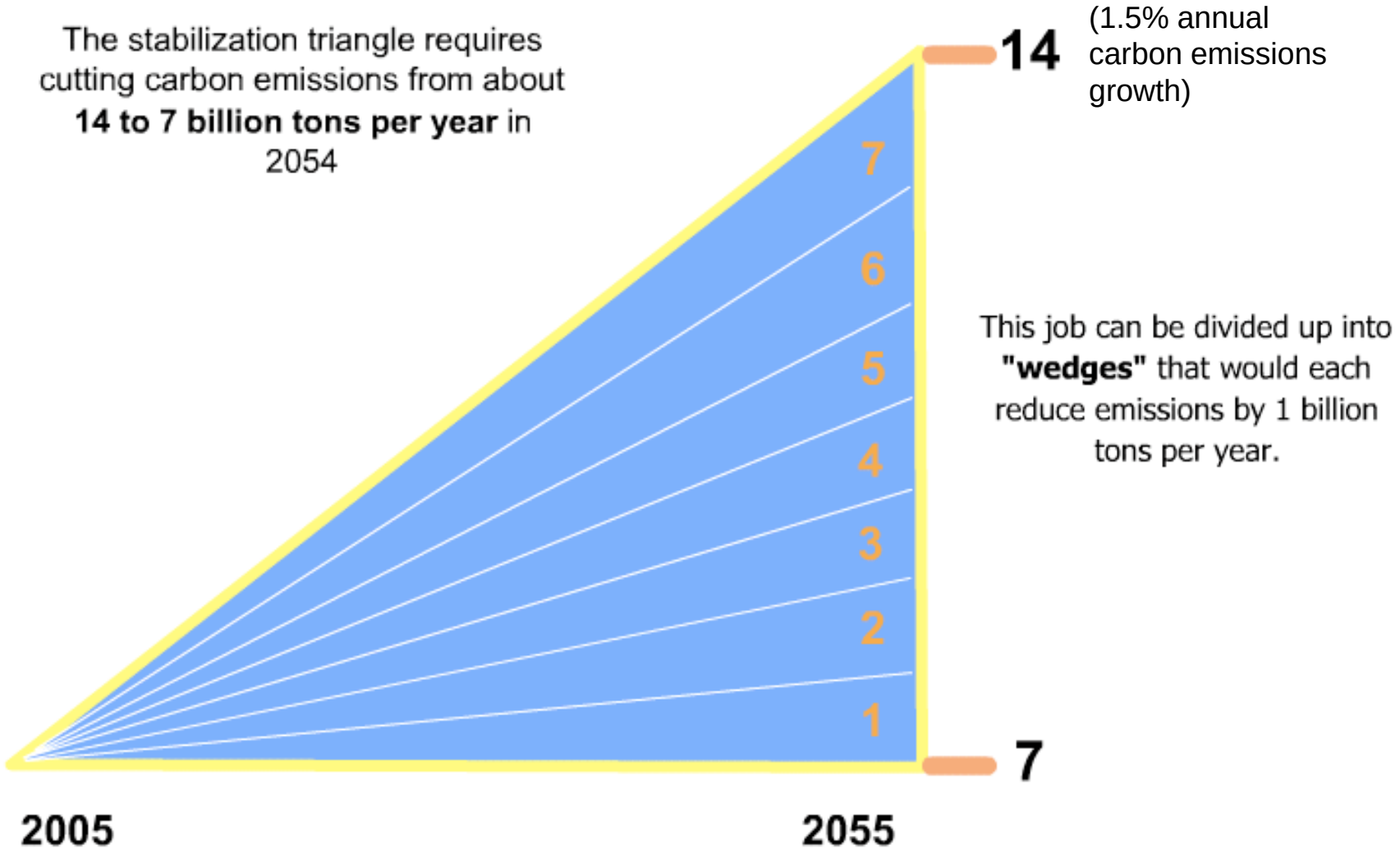
2) Depletion of energy resources (esp. fossil fuels)

3) Geopolitical segregation of energy resources

4) Health-related issues

5) Energy poverty

The Way Forward ?



If carbon emissions were to grow 2% per year then 10 wedges would be needed; and for 3% per year then 18 wedges would be required

"*Stabilization Wedges: Solving the Climate Problem for the next 50 Years with Current Technologies*"
S. Pacala and R. Socolow, Science, August 13, 2004

A wedge could be saved by doubling the fuel economy of the world's cars

A wedge could come from halving the number of miles traveled by car

A wedge would be saved by using best efficiency practices in all residential and commercial buildings

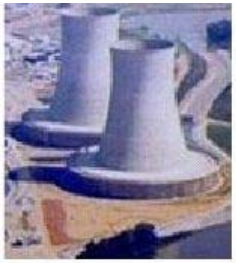
A wedge could be saved by producing current coal-based electricity with twice today's efficiency

Using natural gas instead of coal at 1400 electric plants could save a wedge

Capturing and storing carbon from 800 coal electric plants would save a wedge

Increasing hydrogen fuel production from fossil sources by a factor of 10 could save a wedge with CCS

Capturing and storing carbon from 180 coal-based synfuels plants would save a wedge



Tripling the world's current nuclear capacity would create a wedge

Increasing wind electricity capacity by 50 times would save a wedge

Installing 700 times the current capacity of solar electricity could save a wedge...

Increasing ethanol production by 50 times could save a wedge

A wedge would be saved by eliminating tropical deforestation and doubling the rate of new forest planting

A wedge would also be created by adopting conservation tillage in all agricultural soils

"*Stabilization Wedges: Solving the Climate Problem for the next 50 Years with Current Technologies"*
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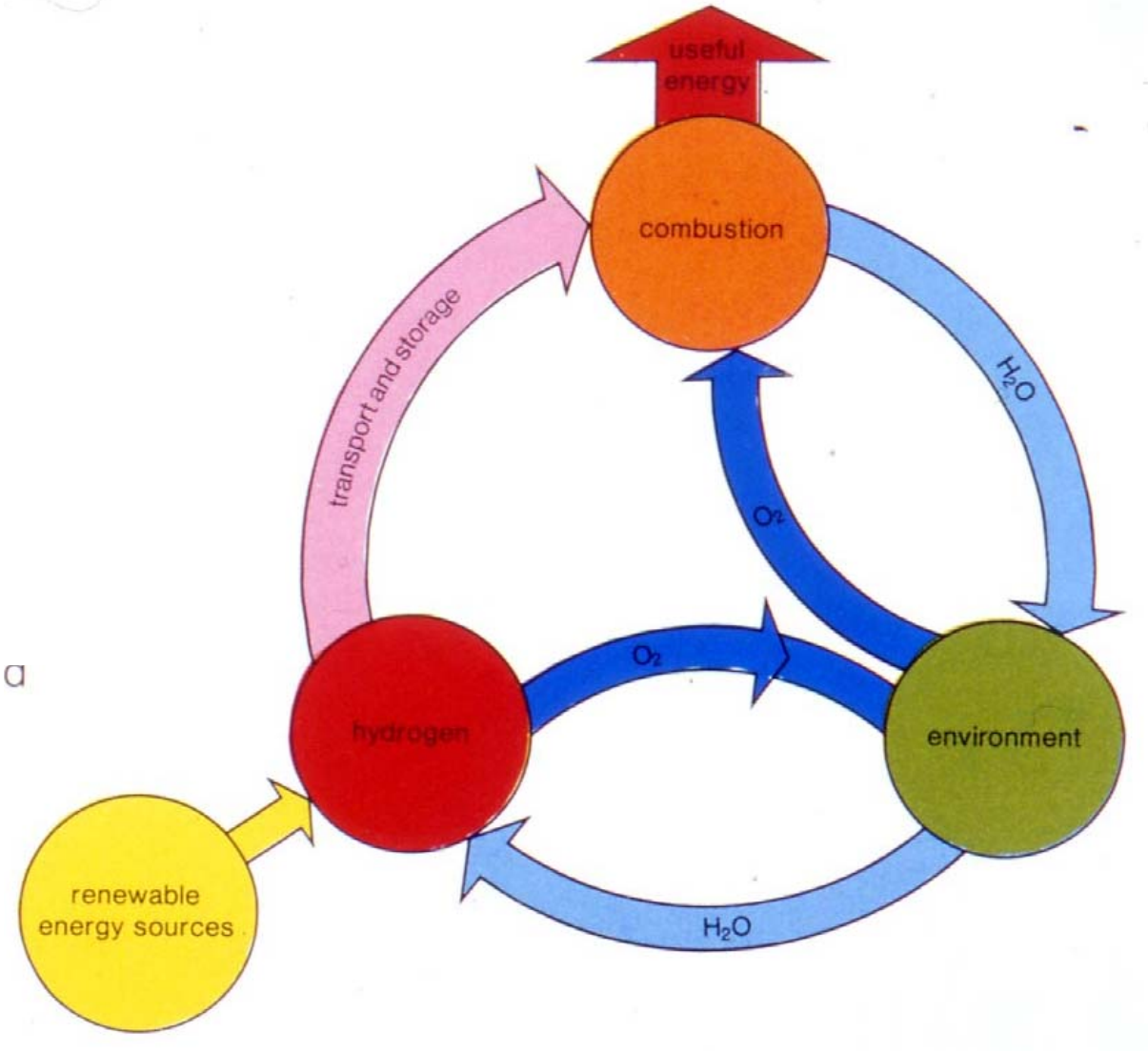
And … … … …

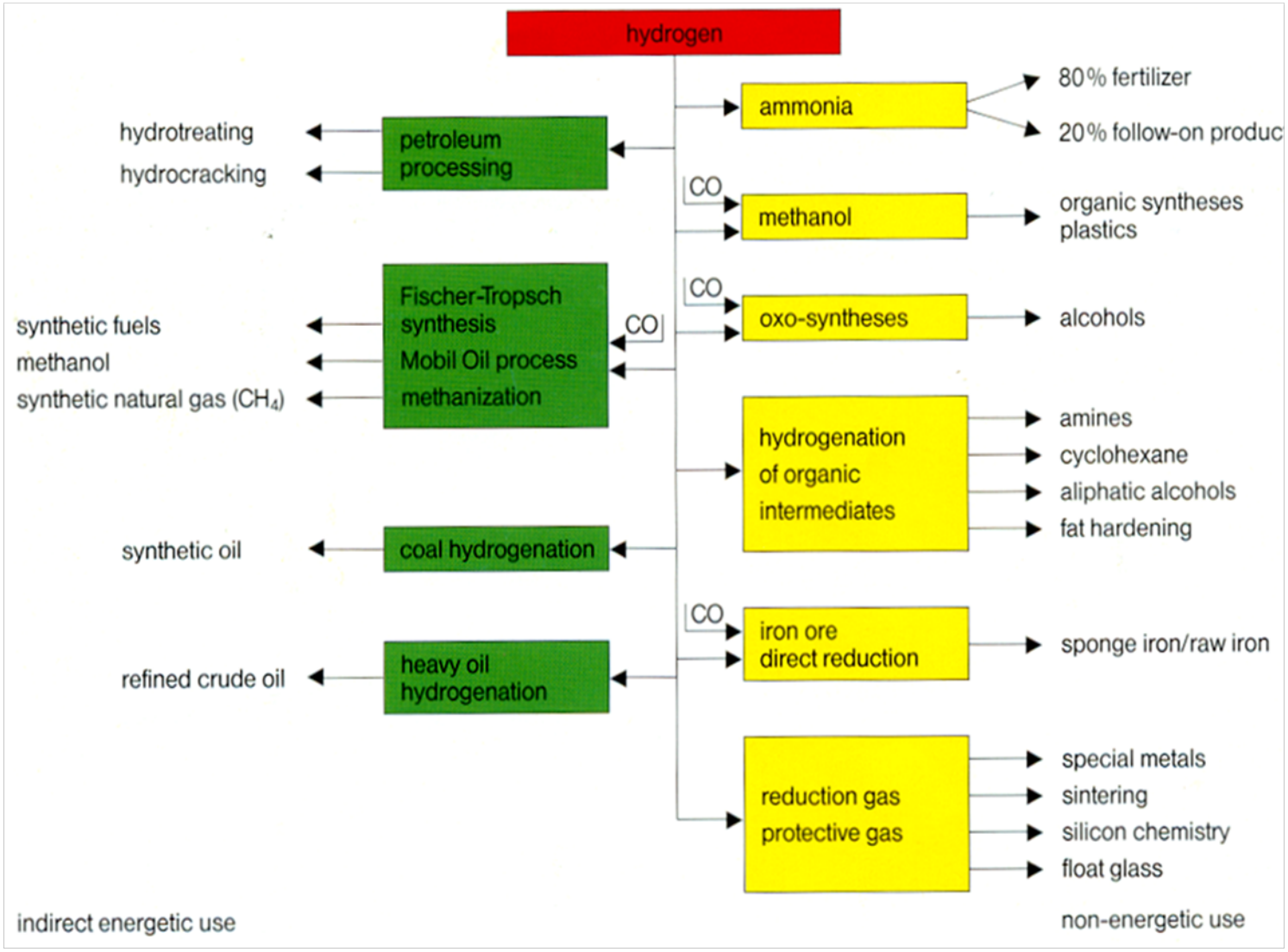
Hydrogen

An Energy System for the Future



Hydrogen Today

Hydrogen as a raw material in industrial synthesis processes



A shuttle launch requires 100 tonnes of hydrogen in 8 minutes. This is equivalent to 13,000 GJ which would propel an average car 100 times around the earth.

World Production of Hydrogen

Origin	***Billions m^3/year***	***Percent***
Natural Gas	240	48
Oil	150	30
Coal	90	18
Electrolysis	20	4
Total	500	100

Source US DoE

Hydrogen From Methane

- Steam Reformation

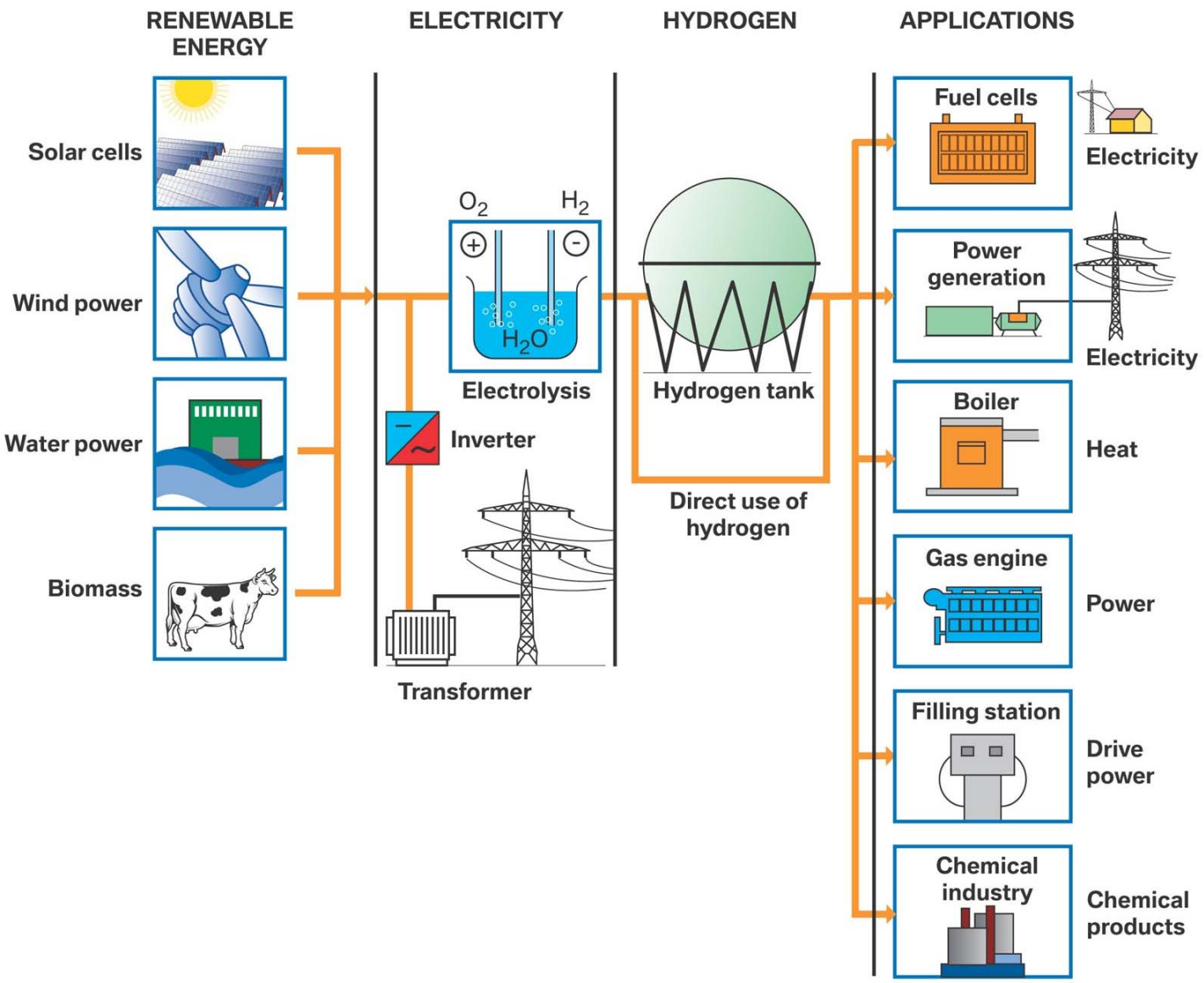
  $CH_4 + H_2O \rightarrow CO + 3H_2$

  $CO + H_2O \rightarrow CO_2 + H_2$

- Still problem of CO_2 emissions
- Same problem for H_2 from oil and coal
- Preferred option for USA?

The long term sustainable solution

Hydrogen from Renewables



Example - Iceland

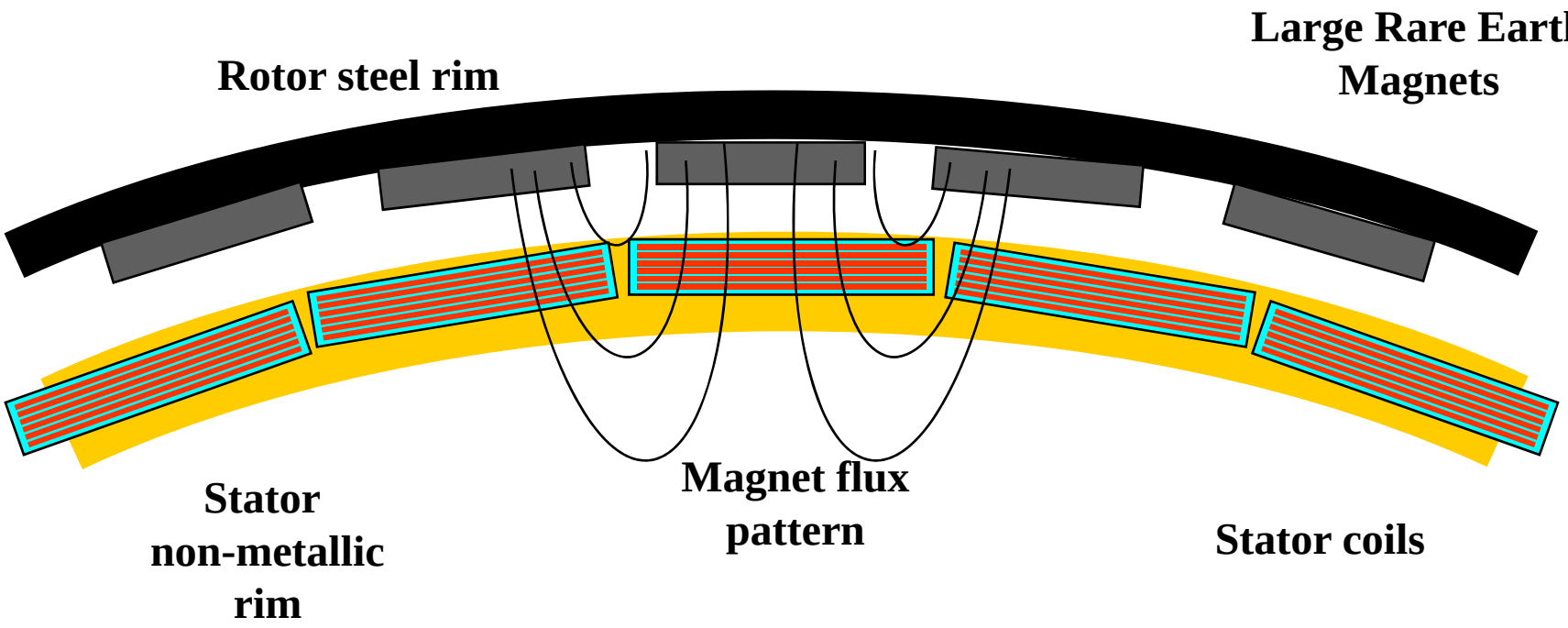
- Shell hydrogen filling station in April 2003
- Plans to move to full ***Hydrogen Economy*** in next 30-40 years
- All energy needs from hydrogen
- Electrolysis of water using renewables
- Geothermal energy

Wind as a major source of sustainable energy

Wind farm at the Altamont Pass in California

An increased role for NdFeB magnets?

Ironless Stator



EGL

NdFeB magnets are currently used extensively in small-scale domestic-type wind generators (e.g. Windsave at B and Q).

There is now a growing trend to use NdFeB magnets in much larger scale wind generators, up to 3 MW (e.g. Enercon).

An annular generator is of primary importance in the gearless system design.

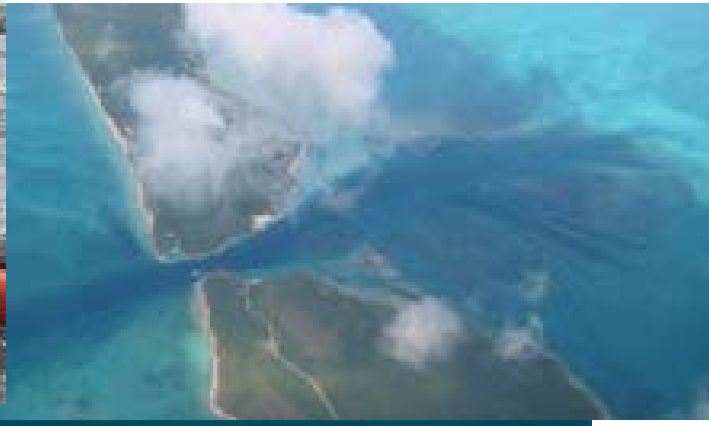
The gentle running of fewer moving components results in minimal material and mechanical wear. Ideal for heavy demands and for long service life.

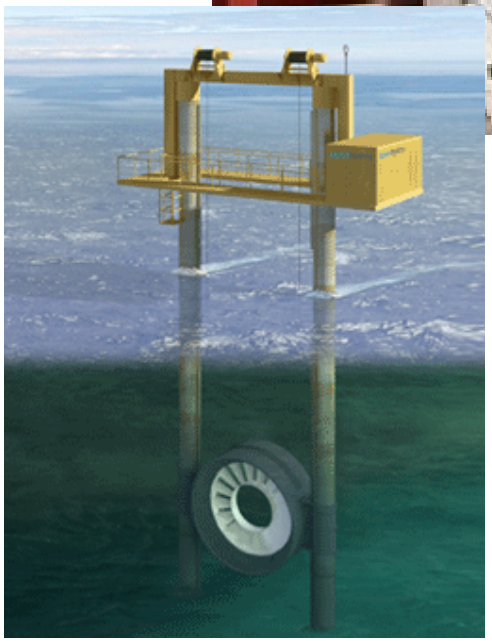
These characteristics are particularly important for "off-shore" generators where the cost of maintenance is a major economic factor.

Tidal generators using permanent magnets are another possibility.

Open-Centre Water Turbine

Aerial view of a tidal flow between two islands





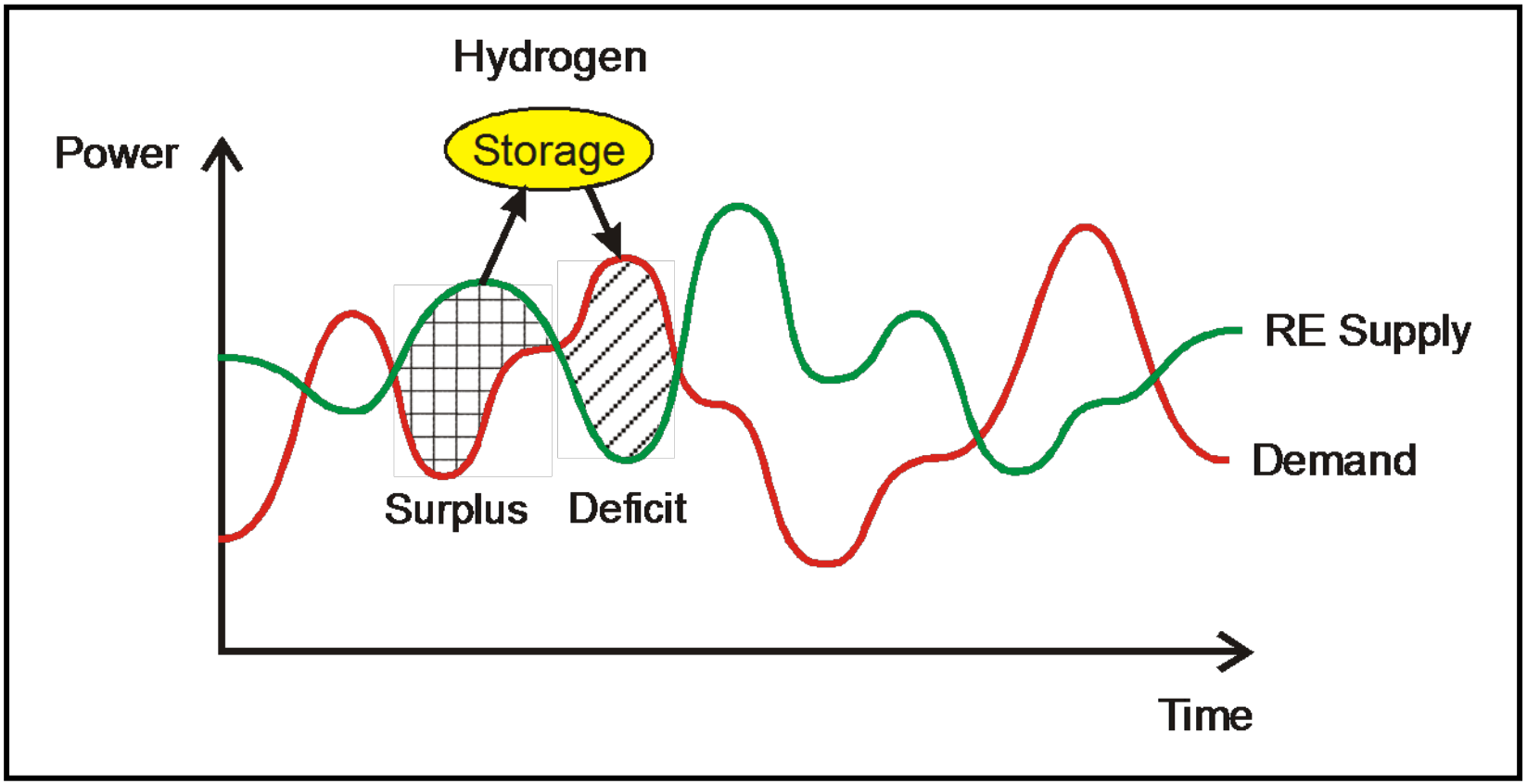
During development, a twin monopile structure will enable the unit to be raised and lowered for demonstration purpose

A gravity base anchors the Open-Centre Turbine to the seabed

Source: www.openhydro.com

Hydrogen can be employed effectively as a means of energy storage.

Load Matching



- Energy storage is needed (to balance varying supply with varying demand)

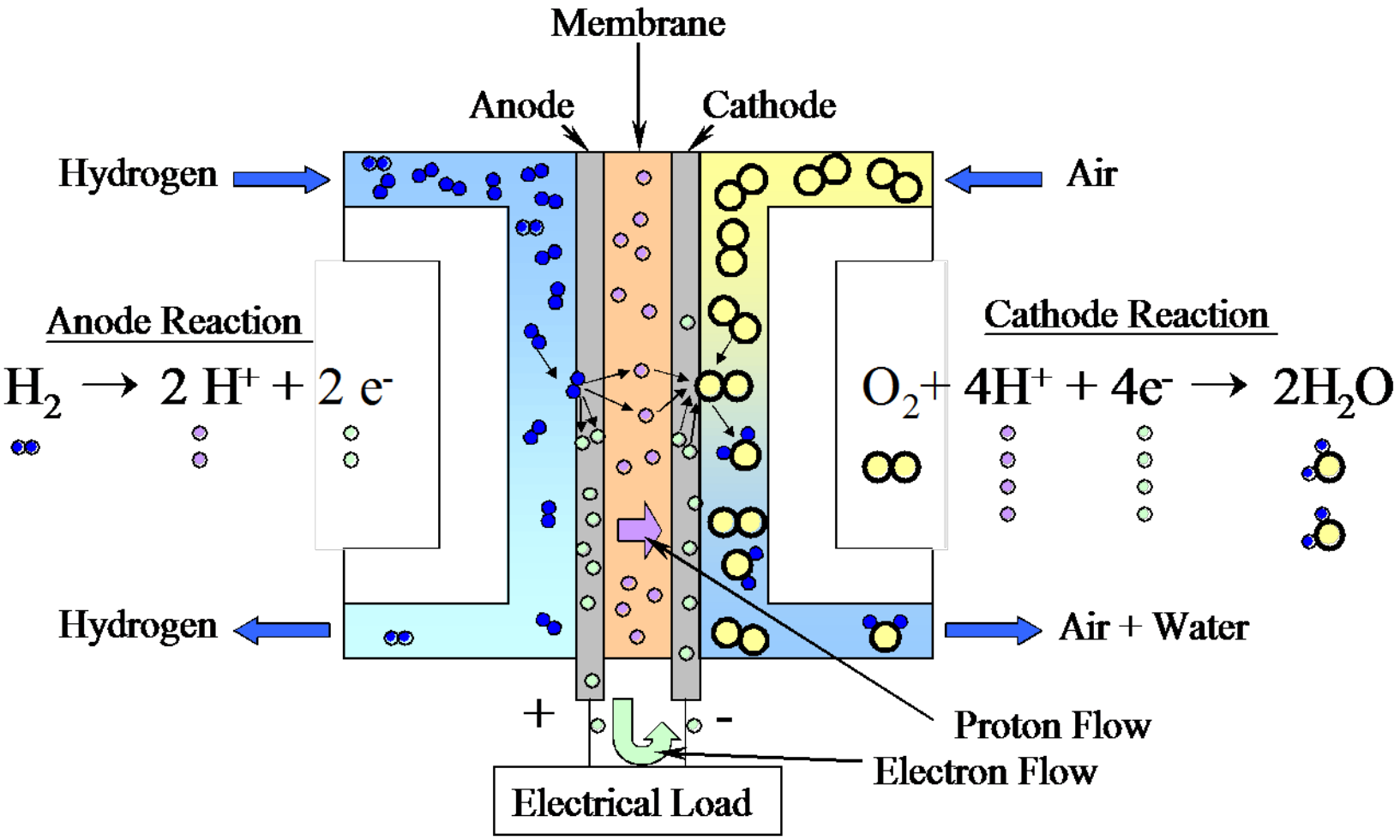
Hydrogen back to electricity

The Fuel Cell

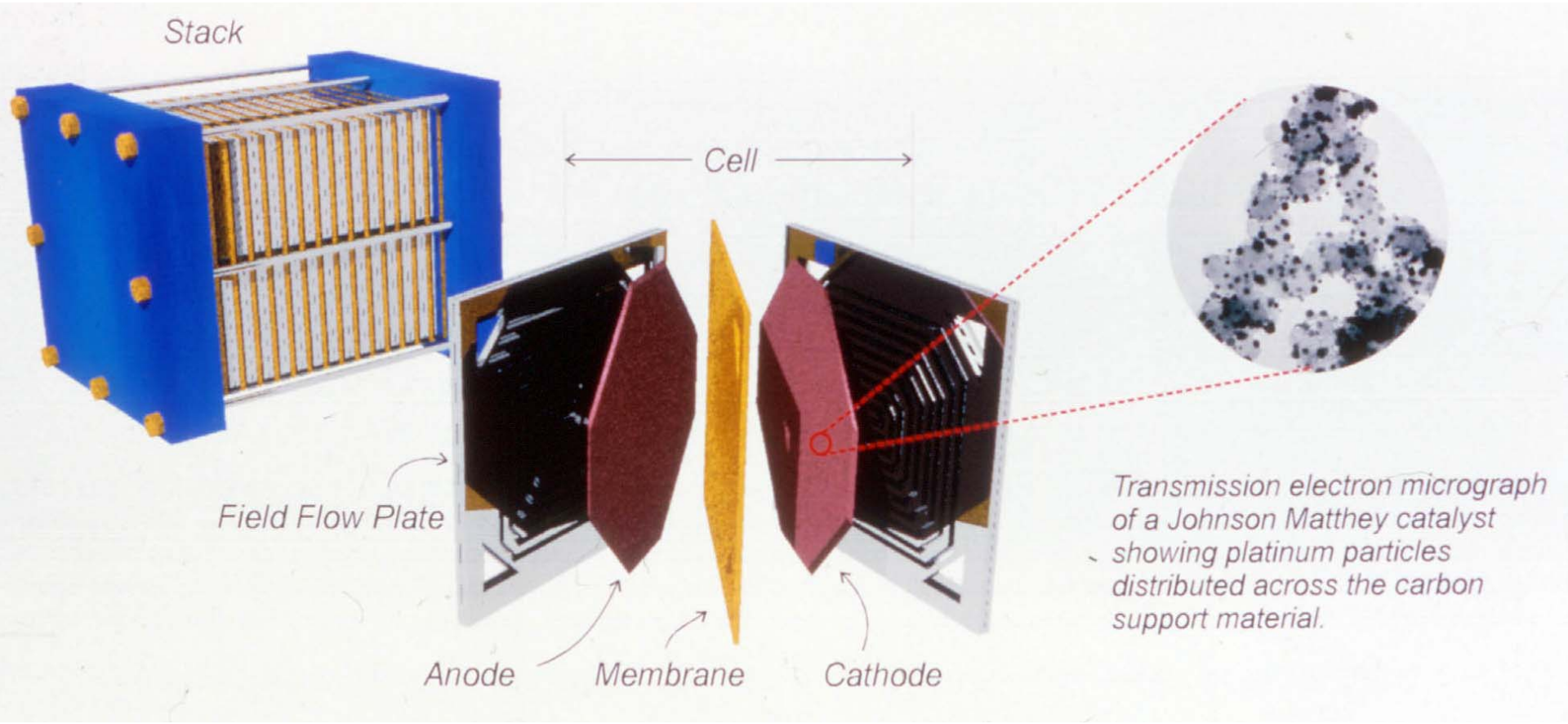
Types of Fuel Cells

Type	Electrolyte	Operating temperature (°C)
Alkaline	**Potassium hydroxide**	**50-90**
Proton exchange membrane	**Polymeric**	**50-125**
Direct methanol	**Sulphuric acid or polymer**	**50-120**
Phosphoric acid	**Orthophosphoric acid**	**190-210**
Molten carbonate	**Lithium/potassium carbonate mixture**	**530-650**
Solid oxide	**Stabilised zirconia**	**900-1000**

PEM Fuel Cell



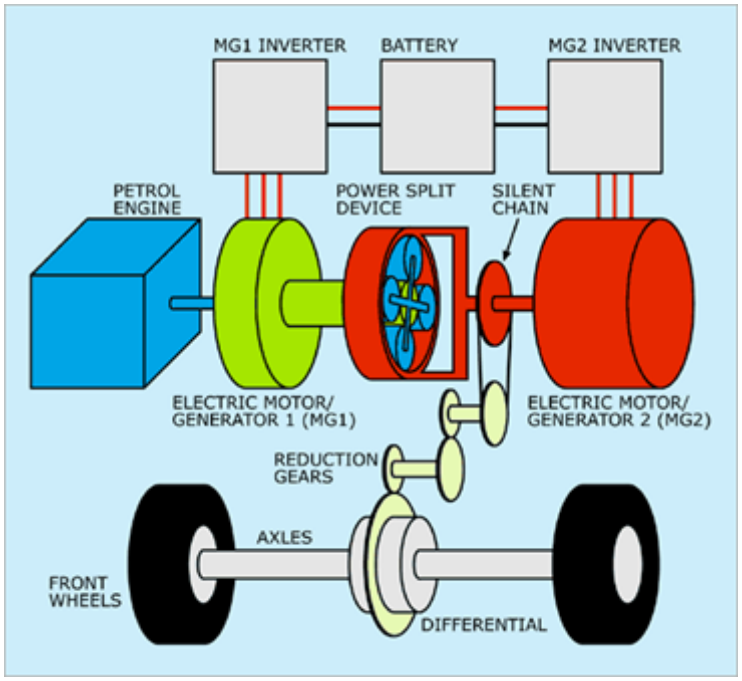
The PEM Fuel Cell



Energy for Propulsion

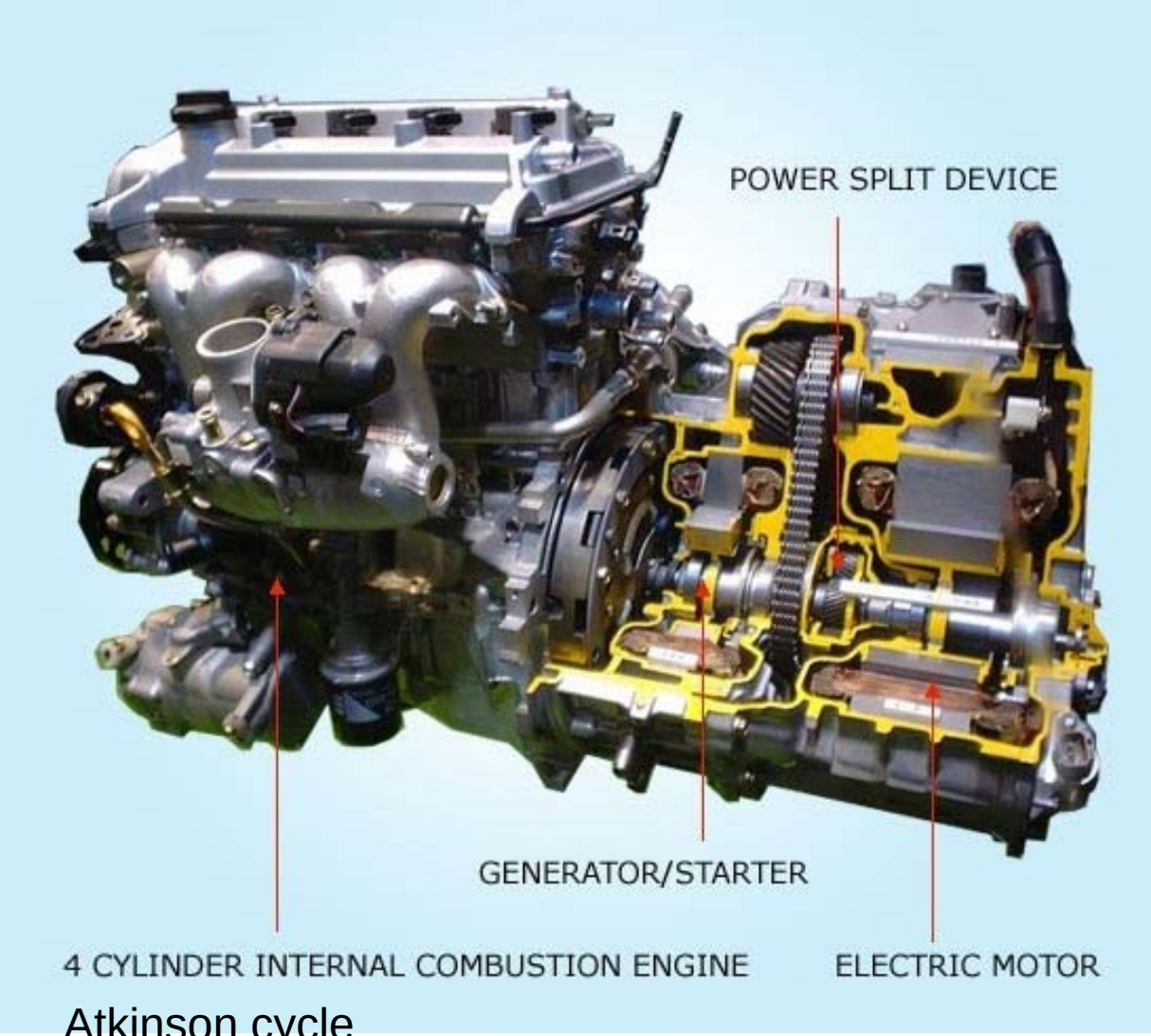
A current success story

Toyota Prius



Introduced in 1997
Sales to date (all models): 552,657
Latest model is 2004 update

Drive-train



Atkinson cycle

Why use a PM-Electric motor?

Cost and Performance Comparison

	Brushed DC	Induction	PM	SR
Specific Torque[1]	3.5	7.4	23.7	6.4
Relative Weight[2]	100	50	25	40
Efficiency	78%	84%	90%	85%
Relative Cost[2]	100	100	150	150

[1]- Torque per unit stator volume (kNm/m^3)
[2]- Brushed DC machine = 100
[3]- Overall efficiency of motor and power electronics

Source: J.G. West - IEE Power Division Colloquium Digest 1993/080

Comments:

- Highly influenced by size (particularly torque and efficiency figures)
- Costs based on potential costs rather than current

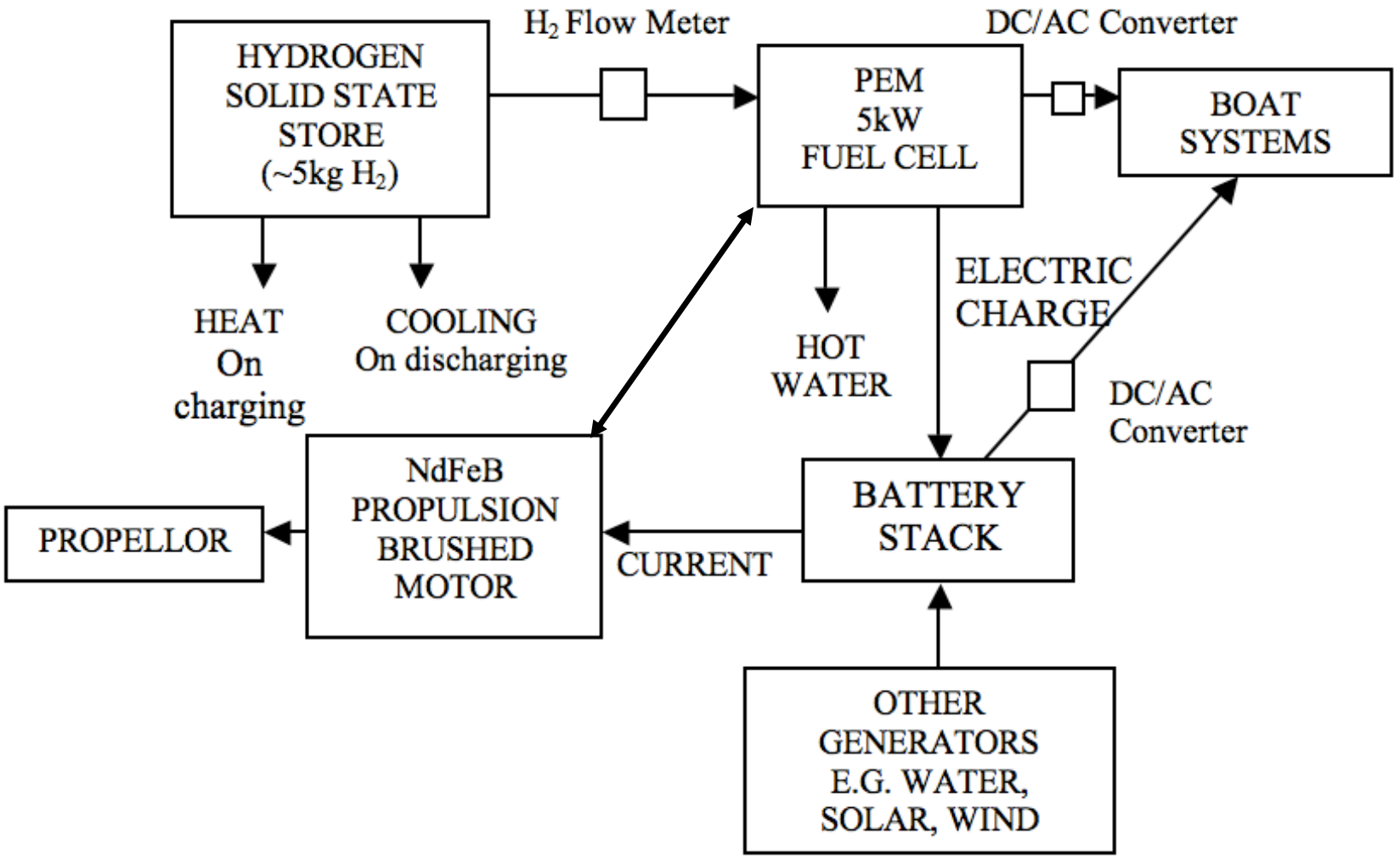
The canal boat demonstrator (The Protium Project)

PEM Fuel Cell

Batteries & Motor

- 5 large cylinders, each containing 30 kg of metal hydride power.
- Gives about 2.5 kg of hydrogen.
- Operating pressure is < 10 bar

Block Diagram Of The Energy System Aboard The Canal Boat

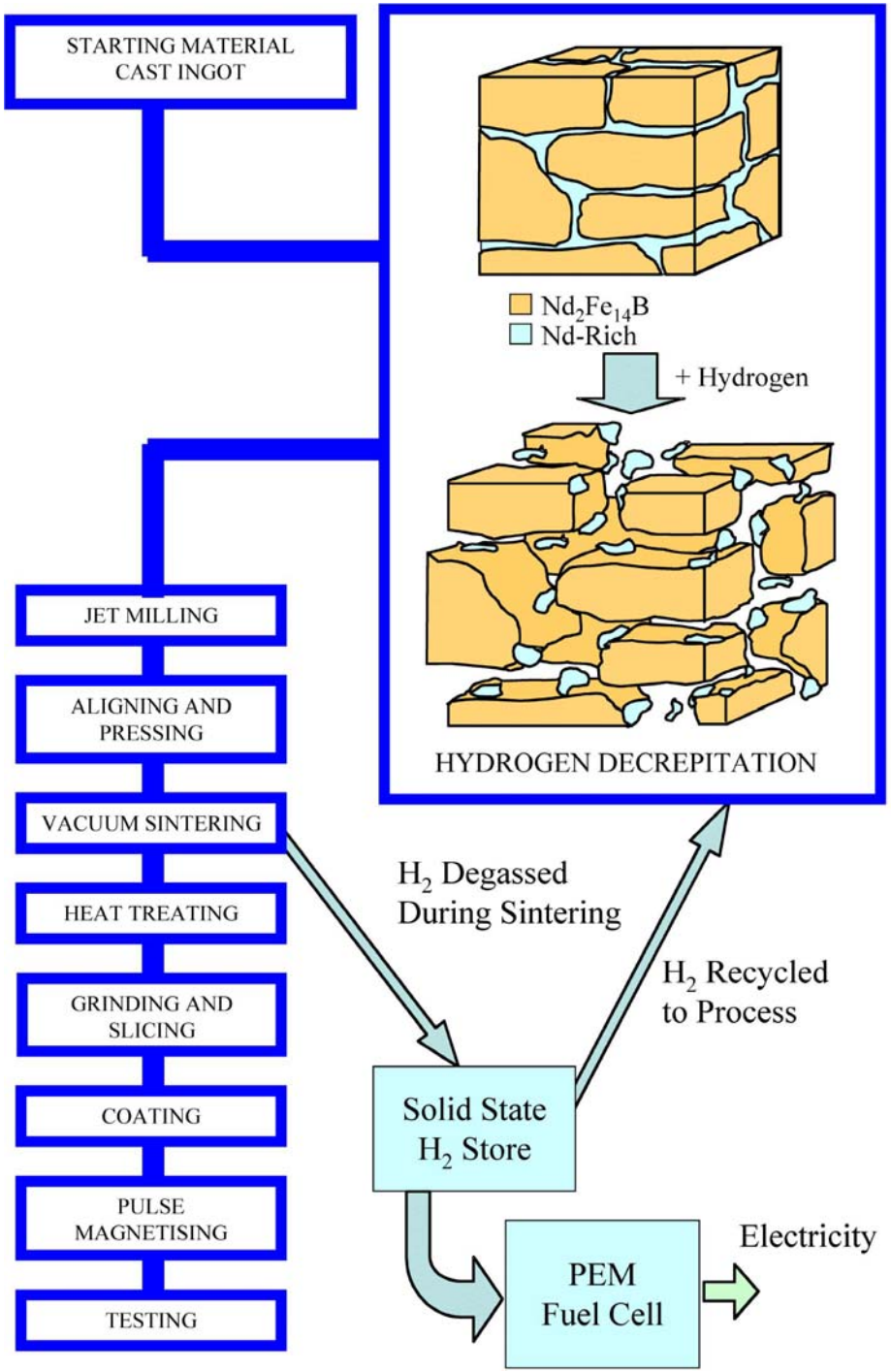


Magnets will also play a major role in improving energy efficiency. Could well be driven by legislation. No more B grade appliances?

Hydrogen also plays a vital role in the manufacture of NdFeB magnets

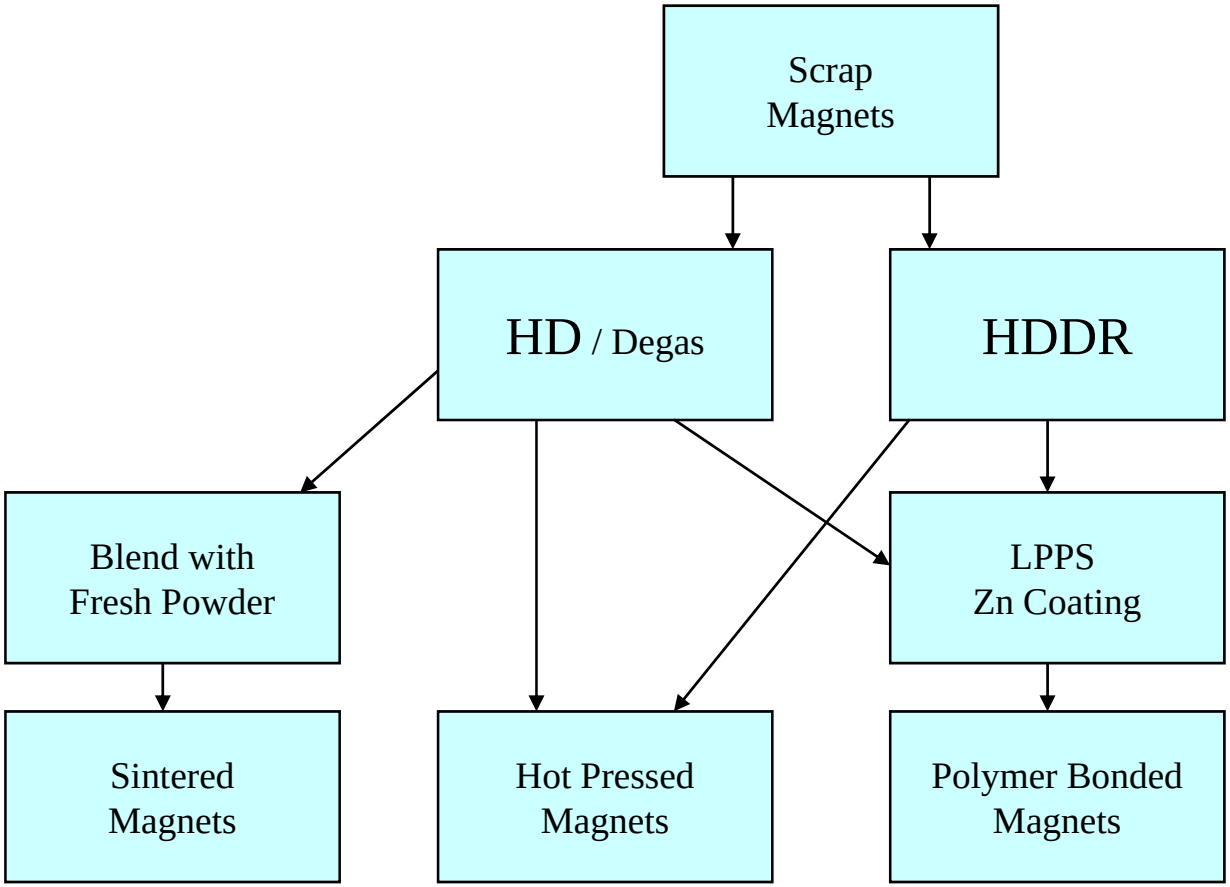
Hydrogen Decrepitation in $Nd_{16}Fe_{76}B_8$ Alloy (8x Normal Speed)

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.


STARTING MATERIAL
CAST INGOT
$Nd_2Fe_{14}B$
Nd-Rich
+ Hydrogen
HYDROGEN DECREPITATION
JET MILLING
ALIGNING AND PRESSING
VACUUM SINTERING
HEAT TREATING
GRINDING AND SLICING
COATING
PULSE MAGNETISING
TESTING
H_2 Degassed During Sintering
H_2 Recycled to Process
Solid State H_2 Store
PEM Fuel Cell
Electricity

NdFeB magnets can also be recycled using hydrogen.

Possible Recycling Routes for NdFeB-type Magnets



Summary

- Hydrogen from sustainable energy or from bio-waste provides a means of energy storage and a fuel for transportation.
- NdFeB magnets provide an efficient means of generating energy and of producing efficient electrical motors and actuators.
- Hydrogen plays a vital role in the manufacture of NdFeB magnets and in recycling of these materials.
- They are indeed partners in the drive to sustainability.

Acknowledgements

Thanks are due to the members of the Hydrogen and Magnets Groups, in the Department of Metallurgy and Materials, and in particular to David Book and Andy Williams for valuable discussions. Thanks are also due to Andy Williams for his help in the preparation of this talk.

Thank you for your attention