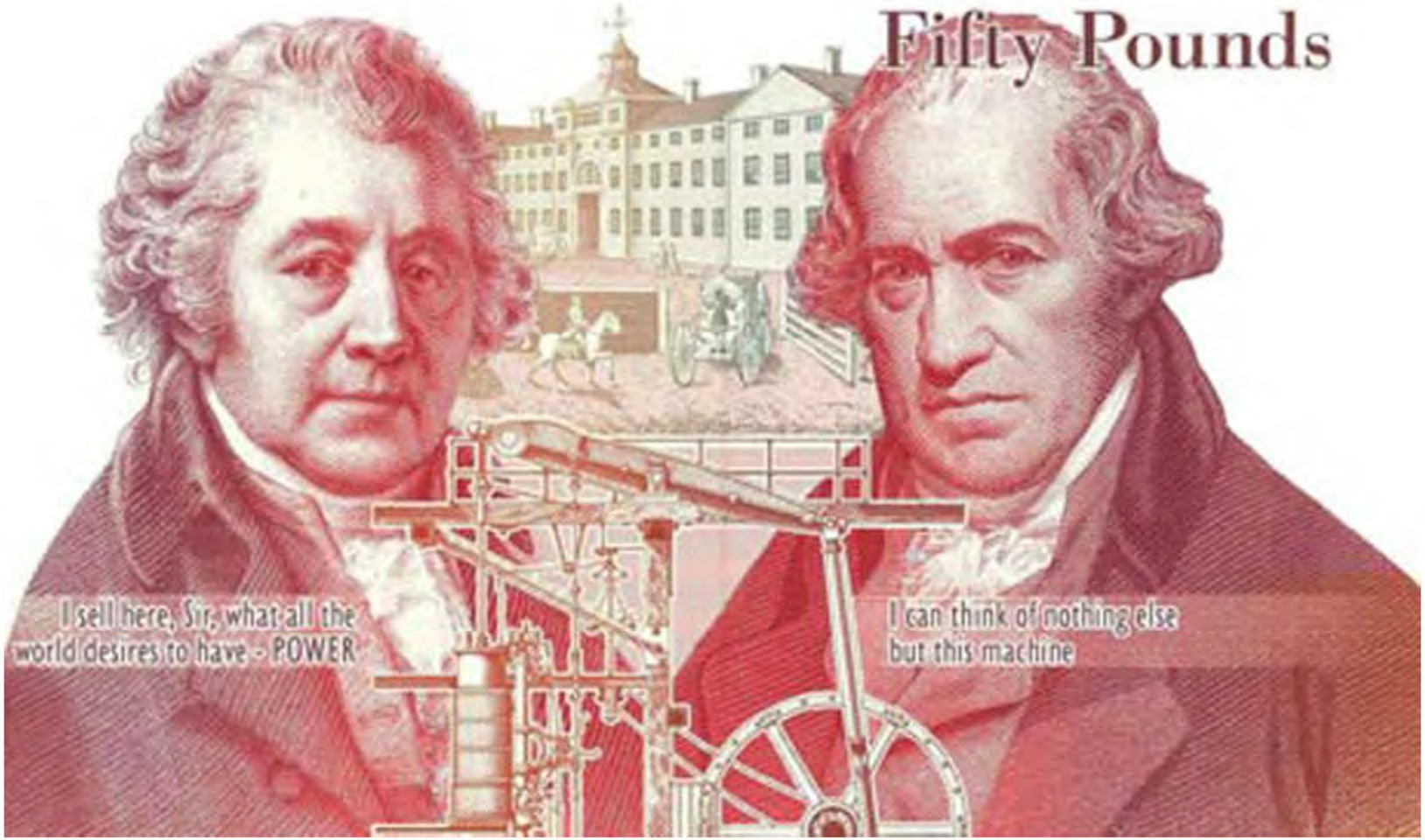
# *Hydrogen,Magnets, Sustainability and the Birmingham Connection.*

*Rex Harris*
*University of Birmingham*
*Low Carbon Meeting*

*June 2012*

**Lunar Society 2011 Boulton & Watt Memorial Lecture**




# Rex Harris: *"Hydrogen, Magnets, sustainability and the Birmingham connection"*

*Boulton: "I sell here,Sir, what all the world desires to have, POWER"*

*Watt: "I can think of nothing else but this machine"*

*A new quotation for 2011.*

*"I sell here, Sir, what all the world desires to have,*

*SECURE, SUSTAINABLE POWER."*

*Wind is a major source of sustainable energy.*

*Wind farm at the Altamont Pass in California*

***Will there be increased role for NdFeB magnets?***

*The biggest single cost associated with off-shore wind generators is servicing and hence reliability is an over-riding consideration. This is why the preferred option is a direct drive rare earth magnet generator rather than a geared induction machine.*

*The gentle running of fewer moving components results in minimal material and mechanical wear. Ideal for heavy demands and for long service life. Applications such as "off-shore" wind turbines.*

# MW rated PM generators

**Permanent magnet wind generator: inner stator**

Design for direct coupling to wind turbine without gear

21 / min rated speed

1.2 MW

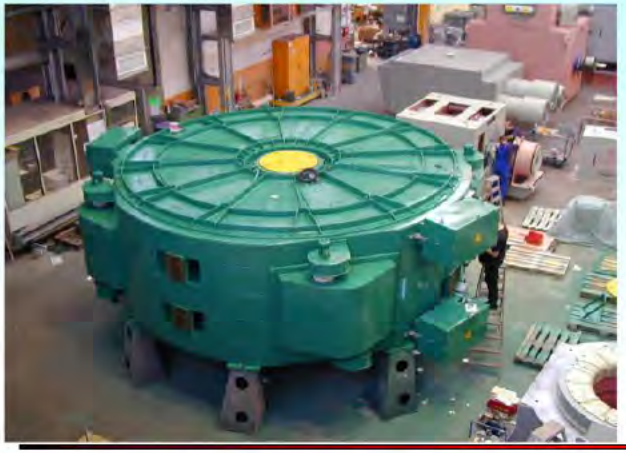
690 V rated voltage

Grid side IGBT-Inverter

Generator side: Diode rectifier and step-up converter

Source:
Innowind, Germany
Goldwind, Urumqi, Xinjiang, China

**Gearless permanent magnet wind generator *Scanwind / Norway* 3 MW, 17/min**



Wind rotor diameter 90 m

Three-blade rotor

Pitch control

Variable speed operation

10 ... 20/min

Gearless drive

IGBT inverter 690 V

*Source:*
*Siemens AG*
*Germany*

**1.2 MW gearless permanent magnet wind generator in operation**

1.2 MW turbine

wind rotor diameter 62 m

pole height 69 m

speed 21/min

pitch control

electrical pitch drives

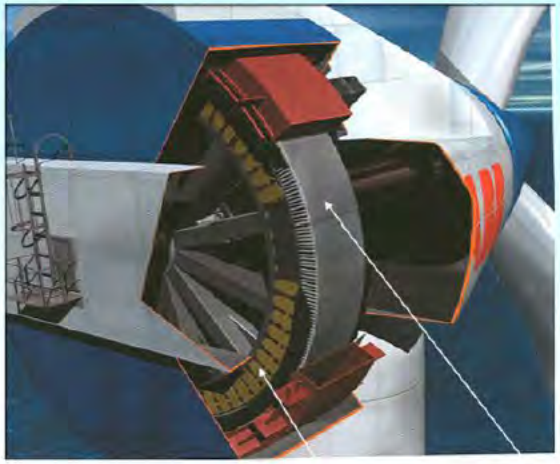
Nacelle and rotor mass: 81 t

Centre pole mass: 96 t

PM generator

Source:
Innowind, Germany
Goldwind, Urumqi, Xinjiang, China

**Gearless permanent magnet wind generator**



- High pole count synchronous generators have a small flux per pole.

- So height of magnetic iron back in stator and rotor may be small = thin ring shape of generator.

- Good possibility to integrate generator with turbine

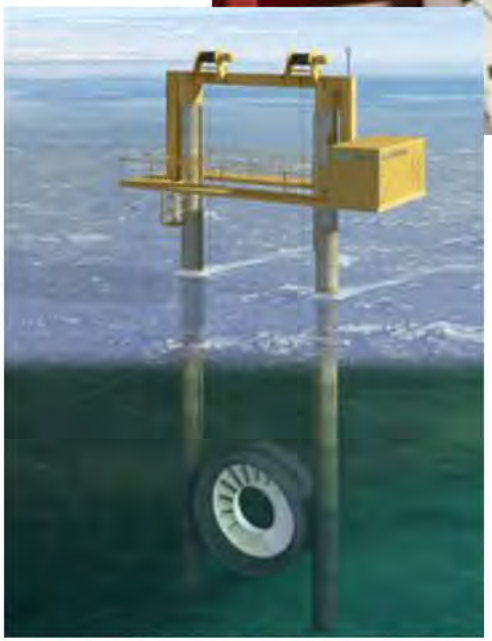
- HV stator winding to save transformer

*These represent potentially massive amounts of NdFeB sintered magnets (~0.7tonne per MW)*

*Tidal generators using NdFeB permanent magnets are another application.*

# Open-Centre Water Turbine

Aerial view of a tidal flow between two islands



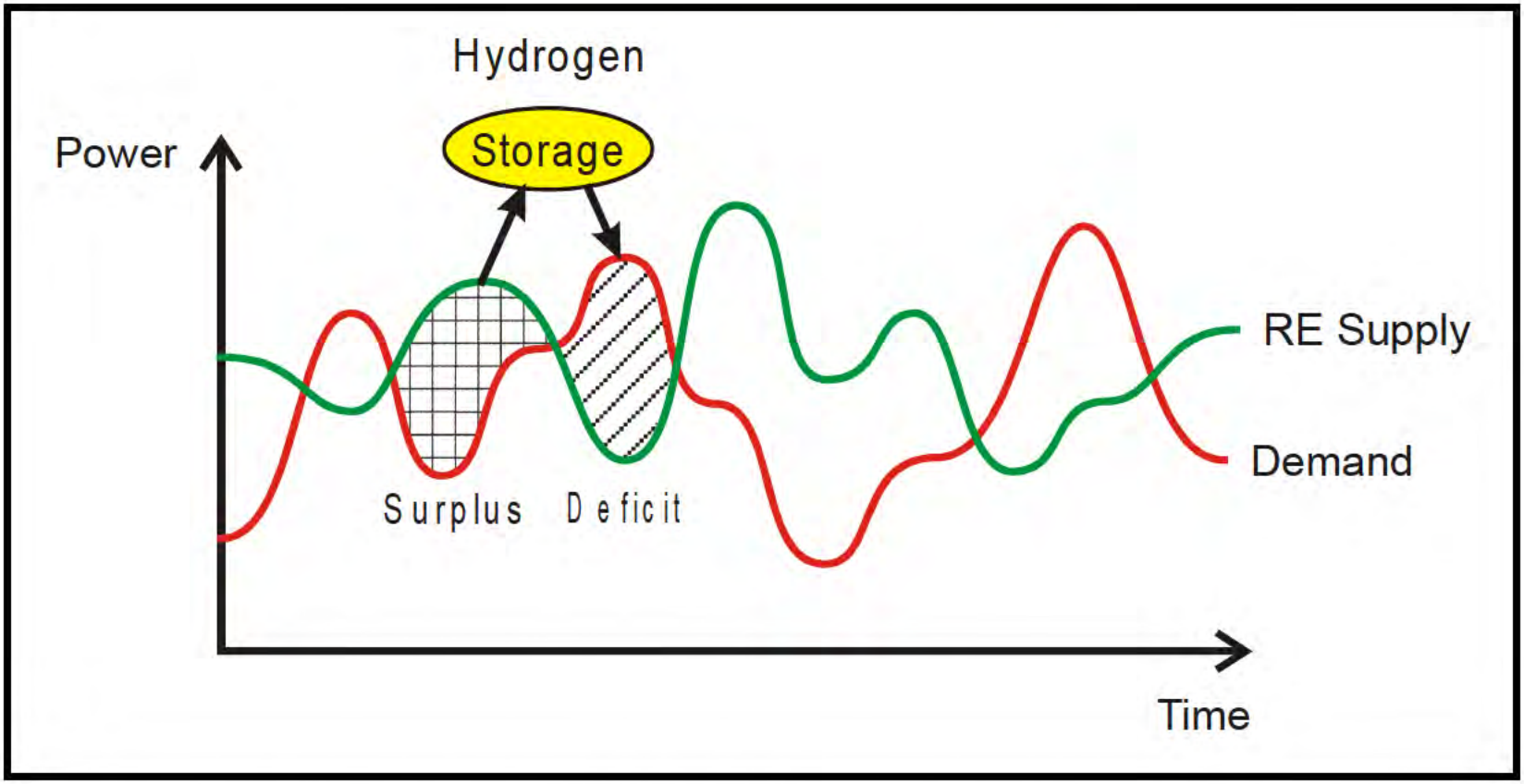
During development, a twin monopile structure will enable the unit to be raised and lowered for demonstration purpose

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

Source: www.openhydro.com

*A major advantage of using hydrogen is that it can be employed effectively as a means of energy storage.*

# *Load Matching*




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

# *Hydrogen back to electricity*

*By means of a Gas Turbine*

*or*

# *The Fuel Cell*

# 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 |

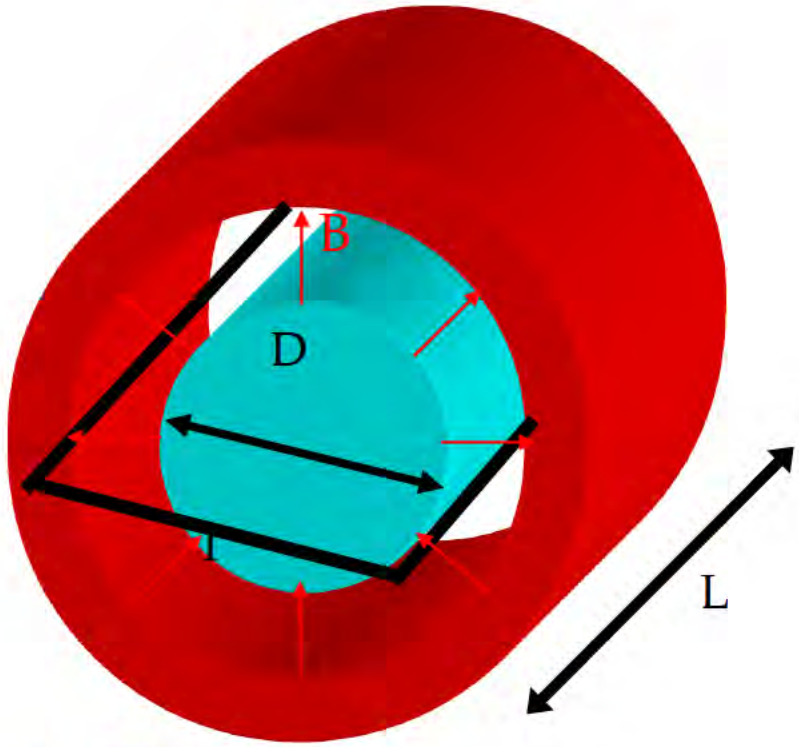
[1]- Torque per unit stator volume ($kNm/m^3$)
[2]- Brushed DC machine = 100
[3]- Overall efficiency of motor and power electronics

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

$$T = \frac{\pi}{2} D^2 L B Q$$




D - Rotor Diameter [m]
L - Rotor Axial Length [m]
B - Average magnetic loading (airgap flux density) [T]
Q - Average electric loading [A/m]

$B \propto B_r$ ( for a fixed magnet length)

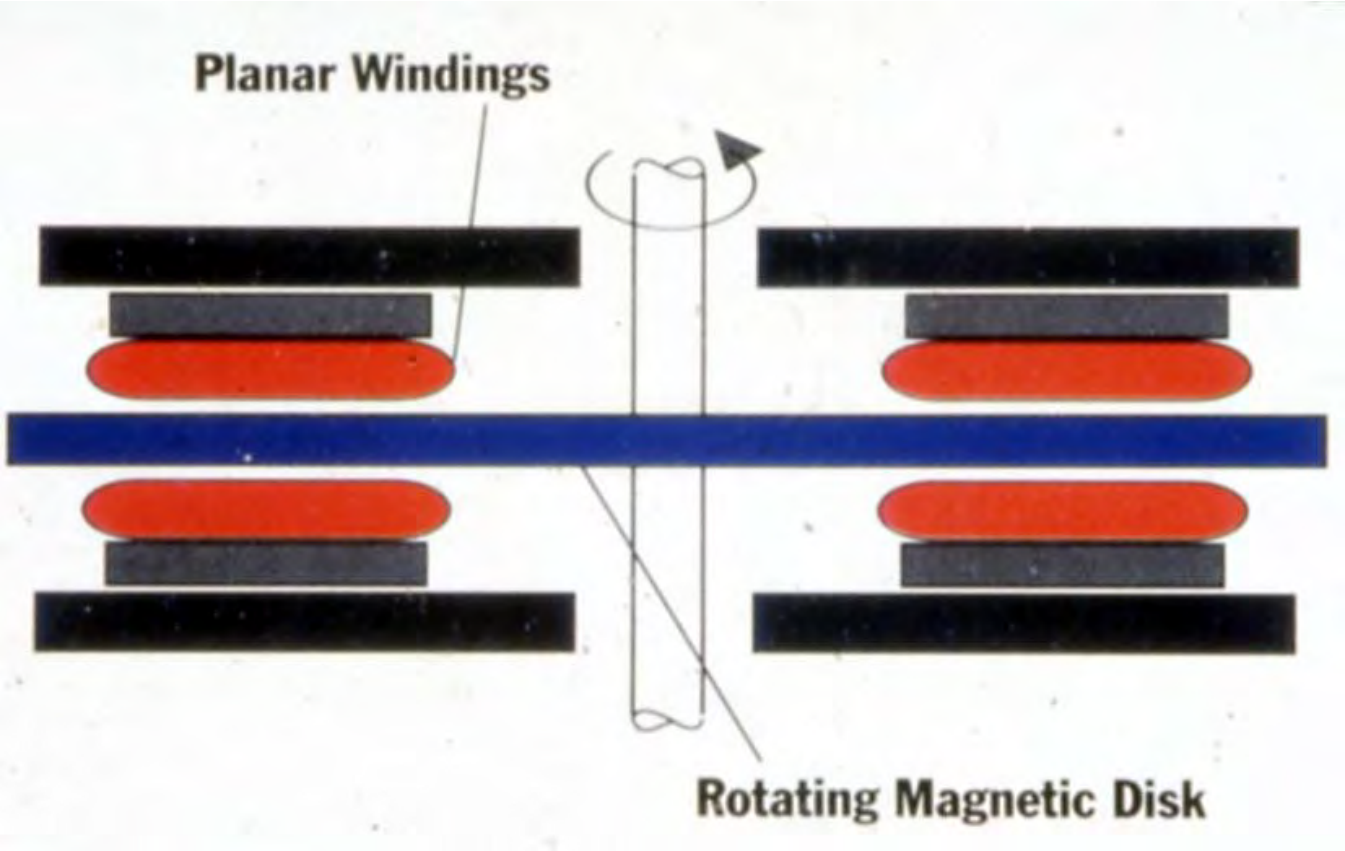
$\Rightarrow$ Rotor Volume $\propto B_r$

But also need coercivity to avoid demagnetisation

*There are obvious technical advantages in using a PM-motor, particularly with regard to the much greater torque and lower weight. However the resource crisis has cast a shadow over these motors.*

*These magnets are ideal for pancake motors suitable for such applications as electric bicycles.*

# *PM Brushless Pancake Motor*



# Application of Nd-Fe-B Magnets in China


## Electric Bicycles

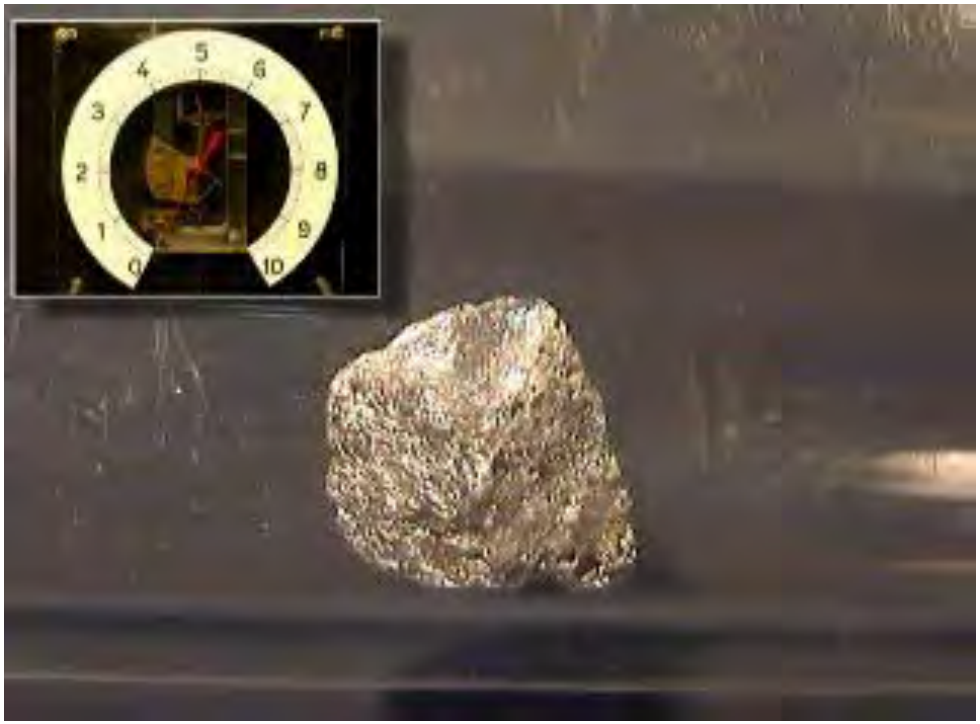
**Output:**

**2004, 5000 k**

Sintered Nd-Fe-B magnets:
about 320 g/bicycle
1600 tonne in 2004.

A NdFeB PM-electric motor is the most efficient means of using the stored electric energy on a vehicle. The motors also have the ability to act as a generator in regenerative mode to recharge the battery.

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


0
1
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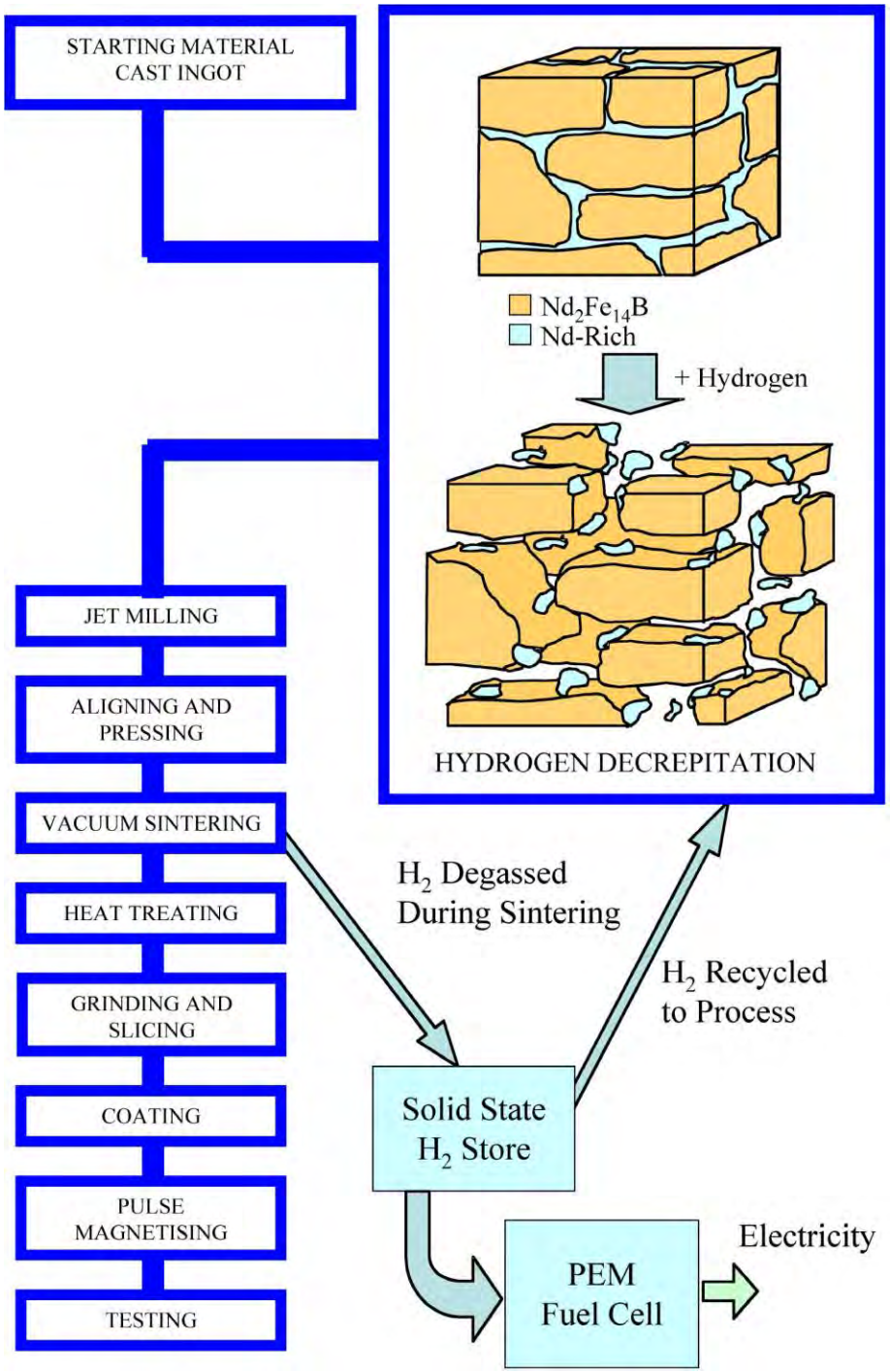
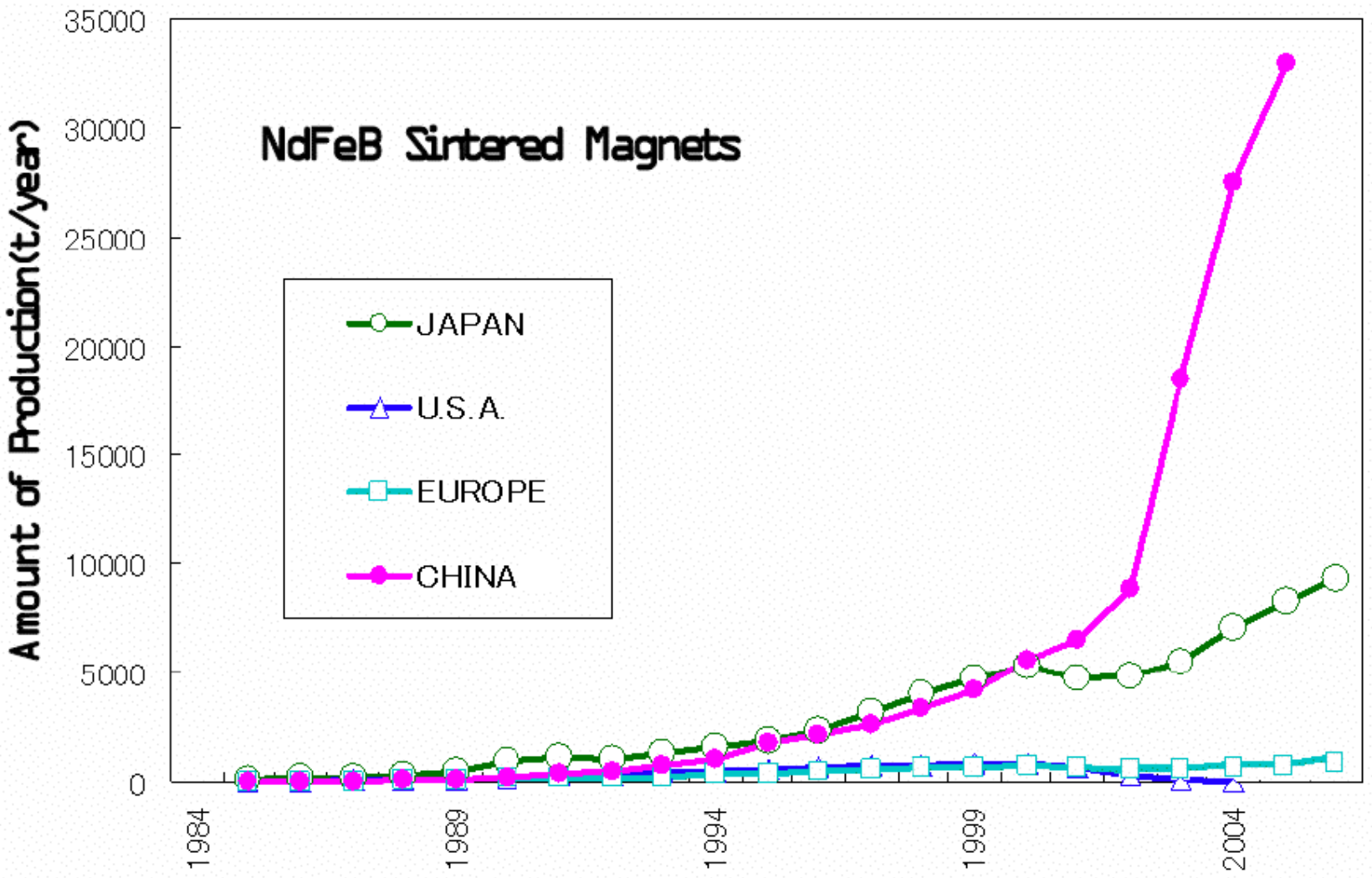
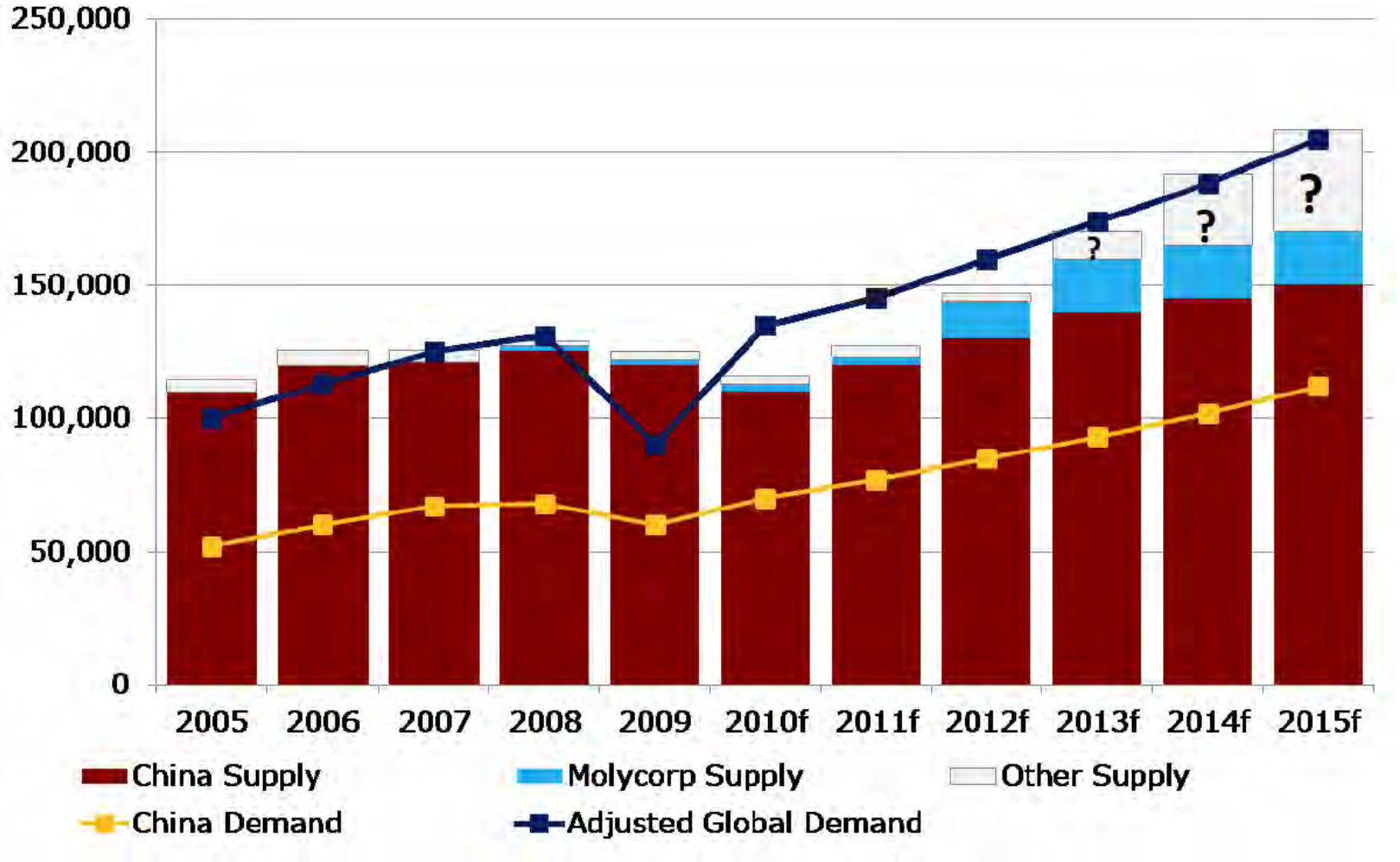

STARTING MATERIAL
CAST INGOT
$Nd_2Fe_{14}B$
Nd-Rich
+ Hydrogen
HYDROGEN DECREPITATION
JET MILLING
ALIGNING AND PRESSING
VACUUM SINTERING
HEAT TREATING
GRINDING AND SLICING
COATING
PULSE MAGNETISING
TESTING
$H_2$ Degassed During Sintering
$H_2$ Recycled to Process
Solid State $H_2$ Store
PEM Fuel Cell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


NdFeB Sintered Magnets
Amount of Production(t/year)
35000
30000
25000
20000
15000
10000
5000
0
1984
1989
1994
1999
2004
JAPAN
U.S.A.
EUROPE
CHINA

*Current figure is ~100,000 tonne*
*Growth rate ~12% per annum*
*Doubling time ~6 years*

*There are major resource issues associated with this vital area of sustainable technology.*

# Global Demand and Supply




Source – Molycorp (Stan Trout) orginal data from IMCOA

# Chinese Rare Earth Oxide Export Quotas

| Year | RE Export Quota | % Change | Demand Outside China (tonnes) | Surplus / Shortfall |
|---|---|---|---|---|
| 2005 | 65,609 | 0% | 48,000t | 17,609 |
| 2006 | 61,821 | -6% | 53,000t | 8,821 |
| 2007 | 59,643 | -4% | 55,000t | 4,643 |
| 2008 | 56,939 | -4.5% | 54,000t | 2,939 |
| 2009 | 50,145 | -12% | 25,000t | 25,145 |
| 2010 | 30,258 | -40% | 53,000t | -22,742 |

Source – 2005-2009, IMCOA; 2010, Metal Pages

*To respond to this crisis there is a pressing need to open-up new rare earth reserves throughout the world and to recycle at the end of life.*

*NdFeB magnets can be recycled using hydrogen and this process has been patented and developed at the University of Birmingham.*

*Some final thoughts…*

*I hope I have convinced you that there will be "Life after oil" but that we do need to get on with the building of the necessary infrastructure!*

*Green hydrogen could be generated by electrolysis using electricity from a NdFeB wind generator.*

*The ultimate sustainable process.*

*The moral dimension.*

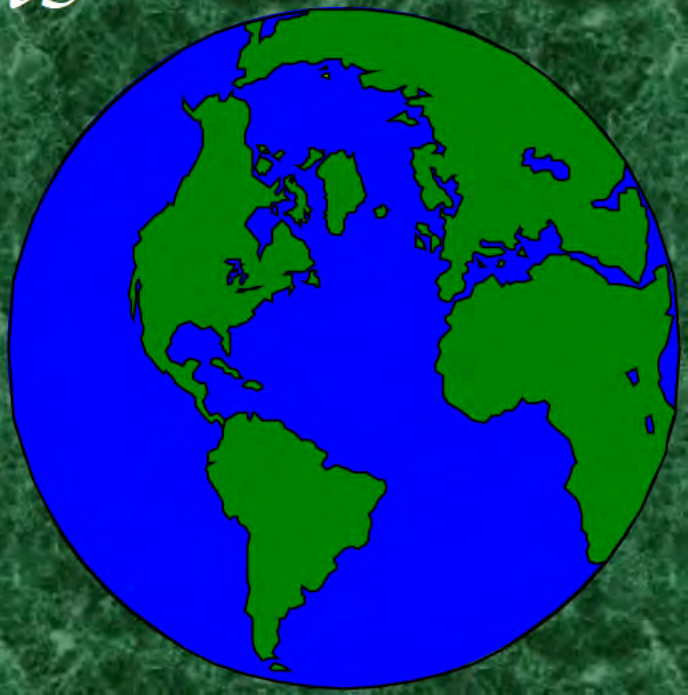
*60 million people in the UK produce more $CO_2$ than the 472 million living in Egypt, Nigeria, Pakistan and Vietnam combined*

*The people who came before us didn't know about climate change and the ones who come after us will be powerless to stop it.*

*Frannay Armstrong*
*Film: The Age of Stupid*

*and finally*

*'Treat the earth well*
*It was not given to us*
*By our parents,*
*It was loaned to us*
*By our children'*
*- Proverb*



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*Thank you for your attention*

www.hydrogen.bham.ac.uk