The **EUROPEAN SCHOOL** on **MAGNETISM**

MAGNETISM.eu
A GATEWAY TO THE EUROPEAN MAGNETICS COMMUNITY

A broad series of fundamental lectures + the latest insights into up-to-date aspects of magnetism with lectures focusing on a special topic

2003: Magnetism of Nanostructured Systems and Hybrid Structures

2005: New experimental approaches to Magnetism

2007: New magnetic materials and their functions

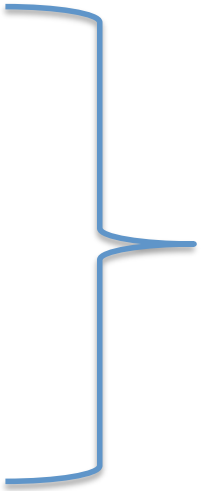
2009: Models in magnetism : from basic aspects to practical uses

2011: Time-dependent phenomena in magnetism

2013: Magnetism for Energy

Magnetism for Energy ?

- **Production**
- **Transmission / Distribution**
- **Storage**
- **Exploitation**



of electrical energy

- Other energy related applications of magnetism

Refrigeration

Actuators

Sensors

…….

Exploiting the link between magnetism and electricity

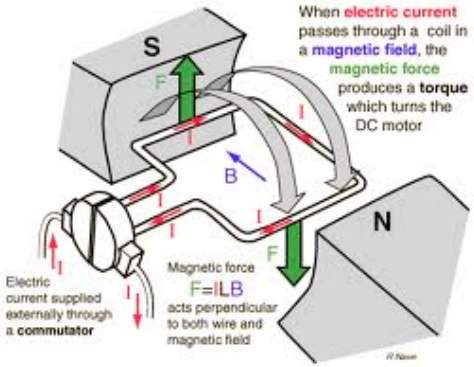
G.W. Jewell

electric motor

electromechanical device that converts

electrical energy ⇒ mechanical energy

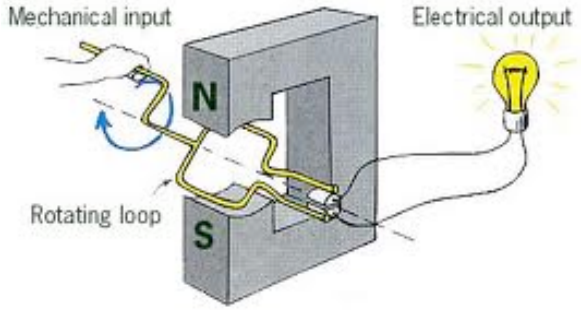
(rotary or linear motion)



electric generator

electromechanical device that converts

mechanical energy ⇒ electrical energy



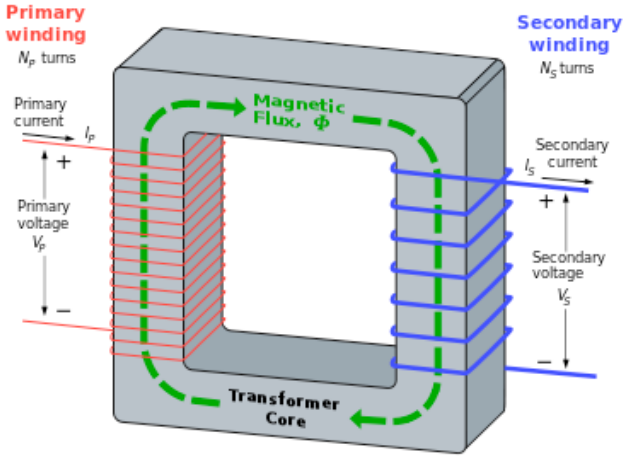
$$\mathbf{F} = I \int d\boldsymbol{\ell} \times \mathbf{B}.$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

W. Wulfhekel

transformer

electrical device that transfers energy by inductive coupling between its winding circuits



Magnetism for Electricity

- **Production**
- **Transmission / Distribution**
- **Storage**
- **Exploitation**

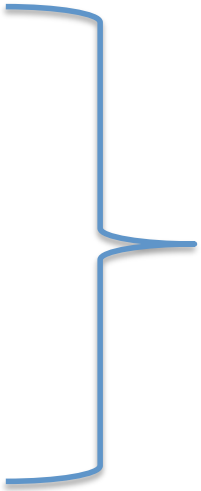
electro-mechanical energy converters
motors / generators

Soft magnets (B, ∇B, dB/dt, μ)

Hard magnets (B, ∇B)

Magnetism for Electricity

- **Production**
- **Transmission / Distribution**
- **Storage**
- **Exploitation**



transformers

Soft magnets (B, dB/dt, μ)

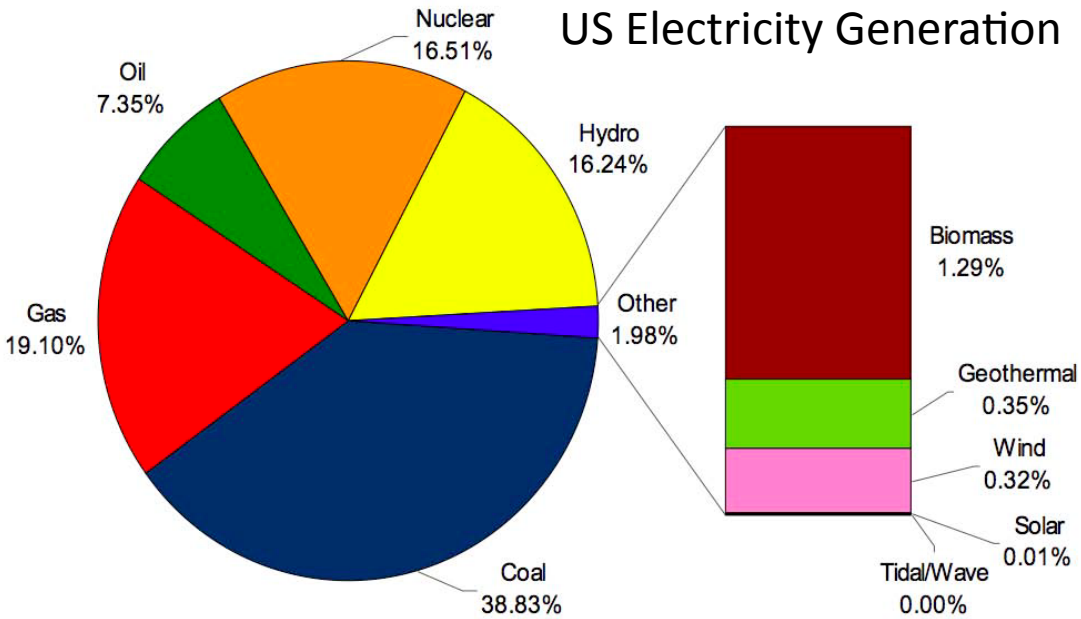
Magnetism for the Production of Electrical Power

Energy sources for electricity production

Fossil fuels (coal, oil, gas…)

Nuclear

Renewable (hydro, wind,
geothermal, solar, biomass, marine….)



Source: IEA WEO

Conversion of mechanical energy to electrical energy using a generator

- **Direct**: hydro, wind, marine..

-**Indirect**:

Combustion (coal, oil, gas…), nuclear, geothermal, solar thermal ⇒ heat ⇒ pressure
⇒ mechanical energy

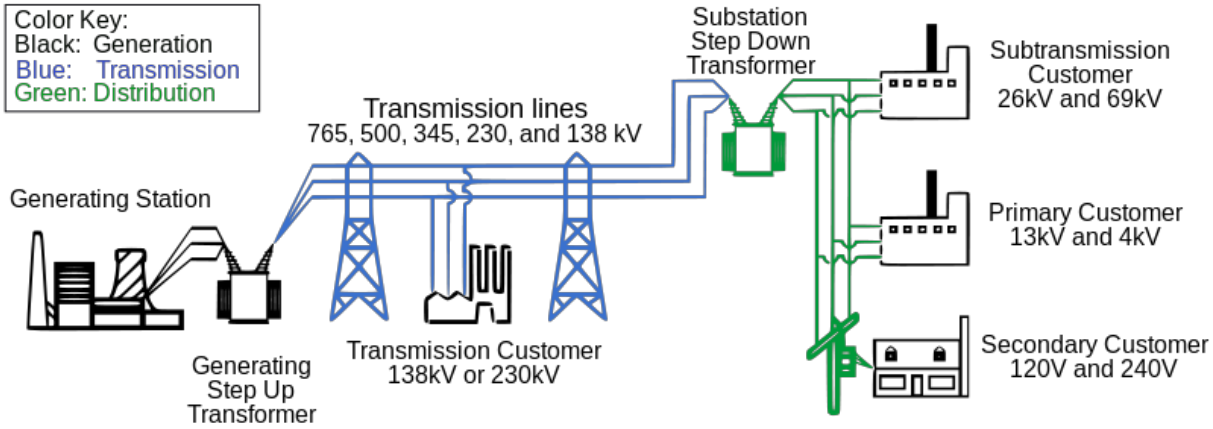
Transformation of V / I

Photo-voltaic

Transmission / Distribution of Electrical Energy

Transformers to step up/down V

Transmit power at high voltage, to minimise Joule losses (I^2R)



Storage of Electrical Energy

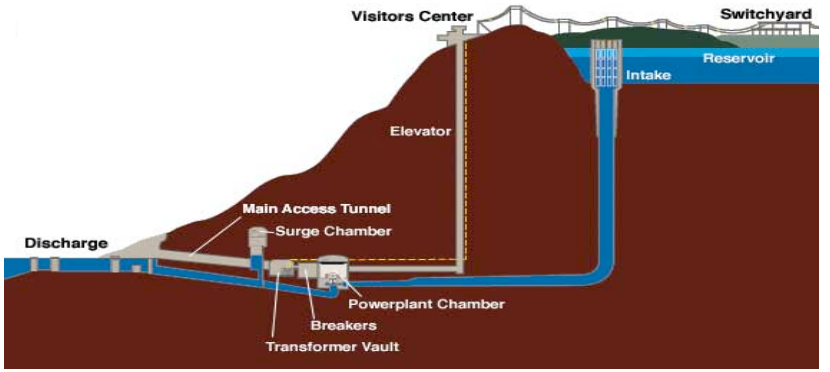
Important for intermitant renewable energies (wind, wave, sun)

energy generated during periods of low energy demand (off-peak)

can be released to meet higher demand during (peak load) periods

Motors / generators for
Pumped-storage hydroelectricity (PSH):
electrical energy ⇔ potential energy

99% of grid storage capacity



Magnetism for Energy ?

- **Production**
- **Transmission / Distribution**
- **Storage**
- **Exploitation**

of electrical energy

Soft magnets
Hard magnets

- Other energy related applications of magnetism

Refrigeration
Actuators
Sensors
…….

Soft magnets
Hard magnets
Magneto-caloric
Magneto-elastic (magnetostrictive, magnetic shape memory)

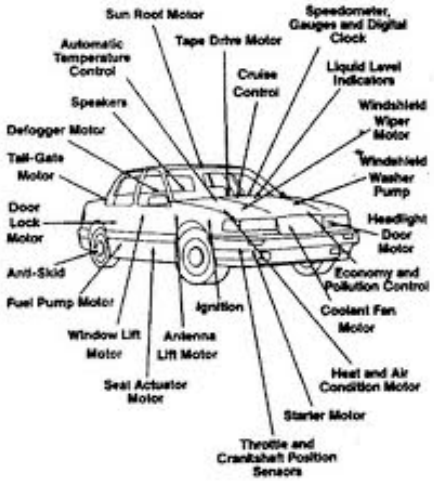
Electric power in cars

Increasing demand for electric power in modern cars….

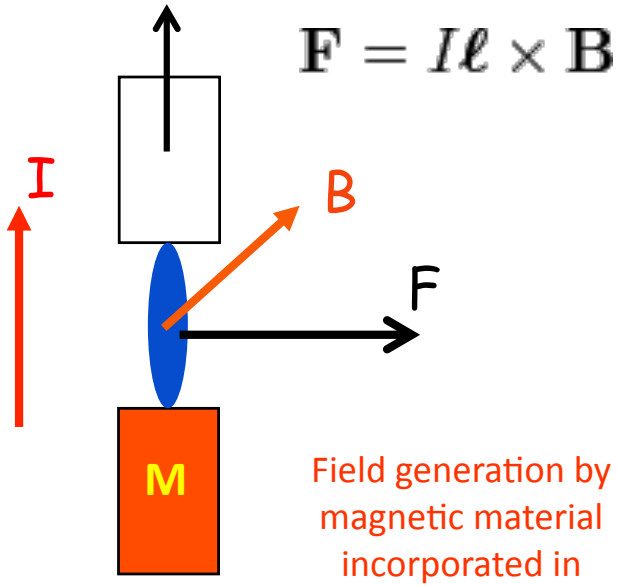
To reduce Joule losses, plan to 42 VDC

But, at this voltage, can have arcing when opening contacts, leading to contact degradation

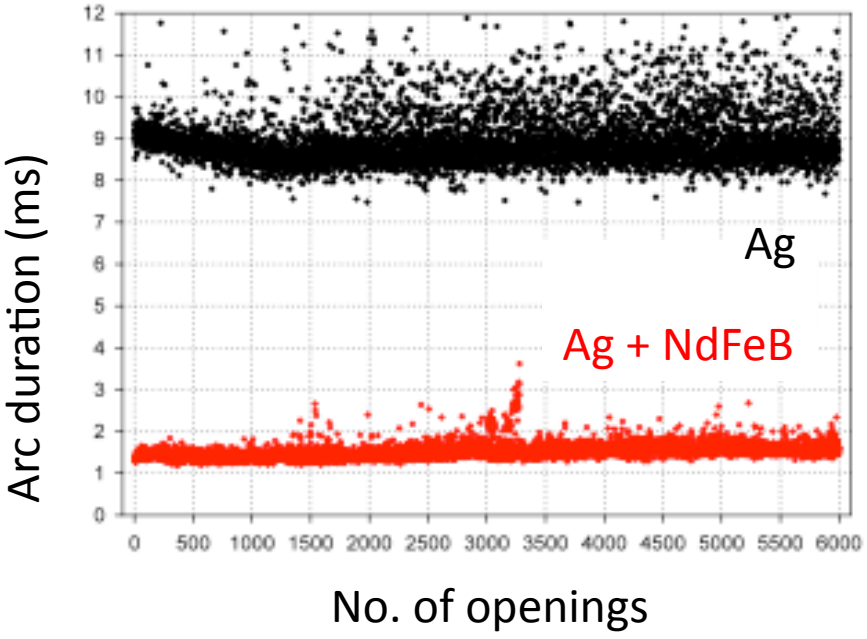
Up to 100 motors in a modern car !



Magnetic blowing to reduce arcing



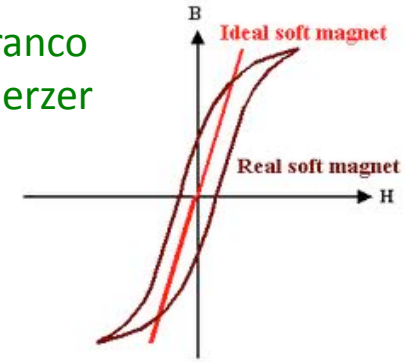
Field generation by magnetic material incorporated in electrical contact

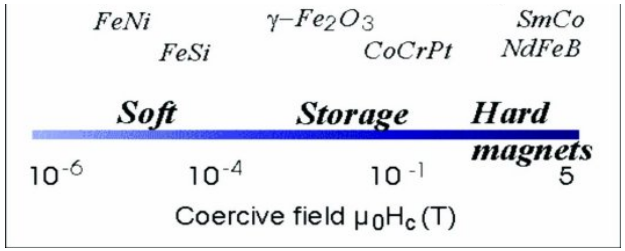


Functional Magnetic Materials

Soft magnets

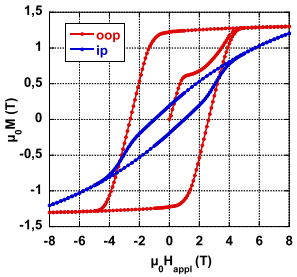
V. Franco
G. Herzer





Hard magnets

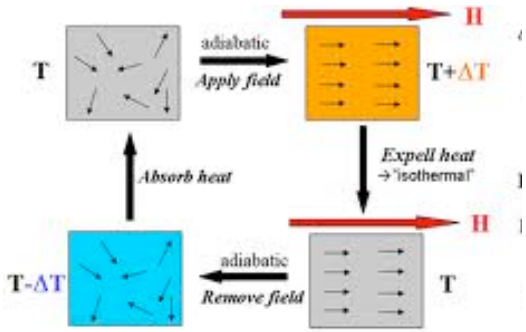
O. Gutfleisch



Magneto-caloric

Entropy change at magnetic phase change
may be associated with a
structural transition

K. Sandeman

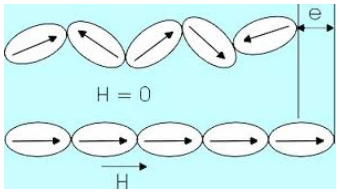


room temperature refrigeration
- enhanced efficiency wrt vapour-compression,
- no greenhouse gas refrigerants

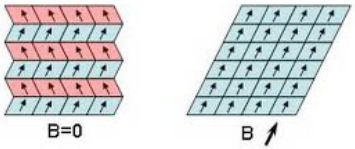
Magneto-elastic

S. Faehler

magnetostriction:
Magnetisation induced
deformation of lattice
(spin-orbit coupling)



magnetic shape memory:
shape change at
magnetic phase change
(T,H induced)



Actuators, transducers

Functional Magnetic Materials

Underlying physics

W. Wulfhekel
M . Kuzmin,
K. Sandeman
O. Fruchart

Materials science

- sample preparation / processing (lab, industry-scale)
- advanced characterisation L. Heyderman, F. Fiorillo
- advanced modelling

Materials criticality

e.g. rare-earths (hard magnets, magnetocalorics) O. Gutfleisch

Search for new materials

Hard magnets: key parameters

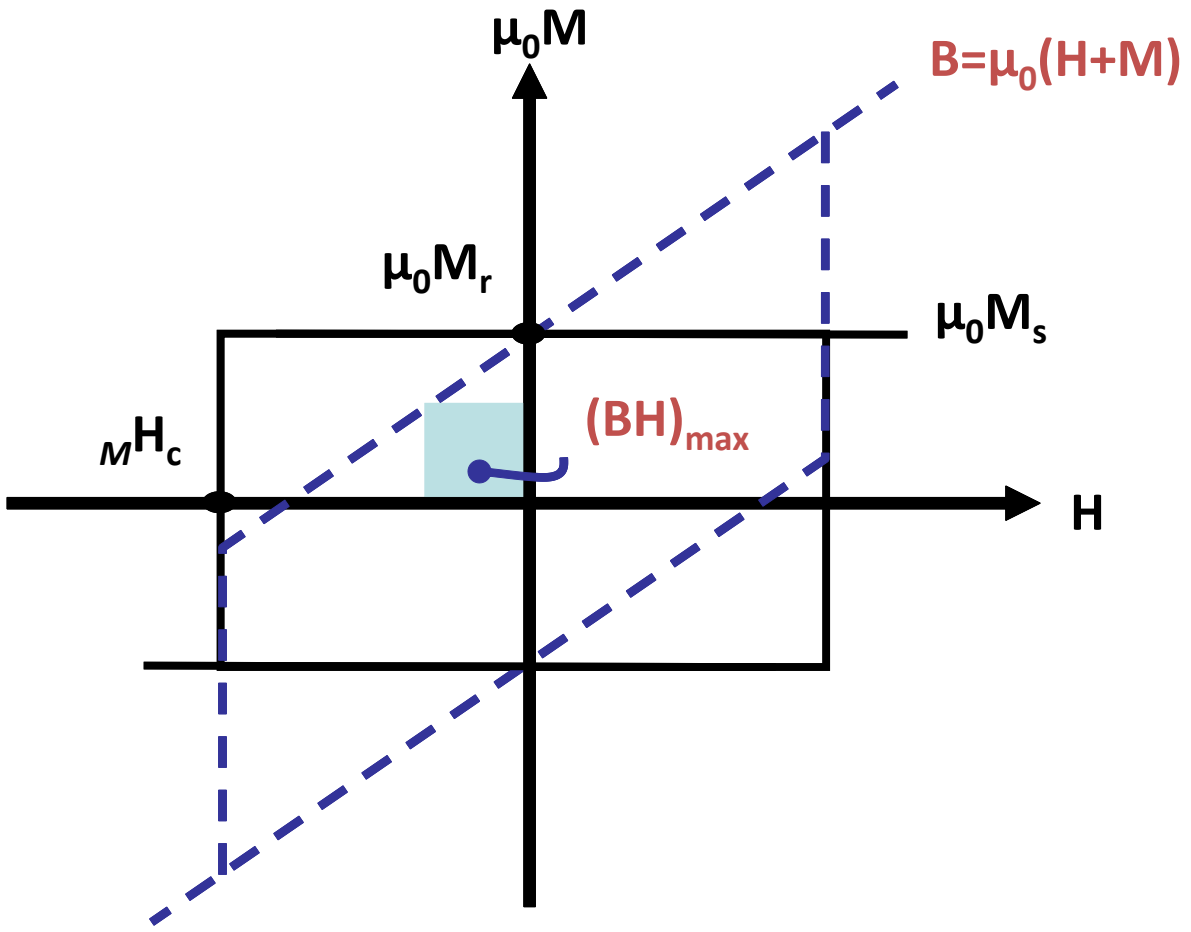
H_c: coercivity

$H_c \leq H_A$ (anisotropy field)

H_c = f (H_A+ microstructure)

↓

defects, demag fields



M_r : remanence

$M_r \leq M_S$ (saturation magnetisation)

M_r = f (M_S + microstructure)

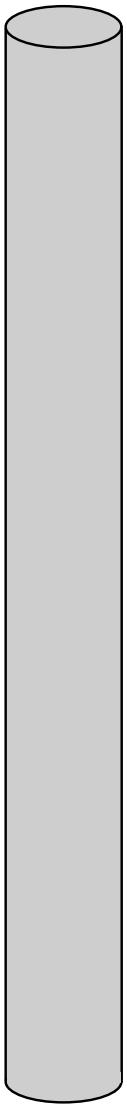
↓

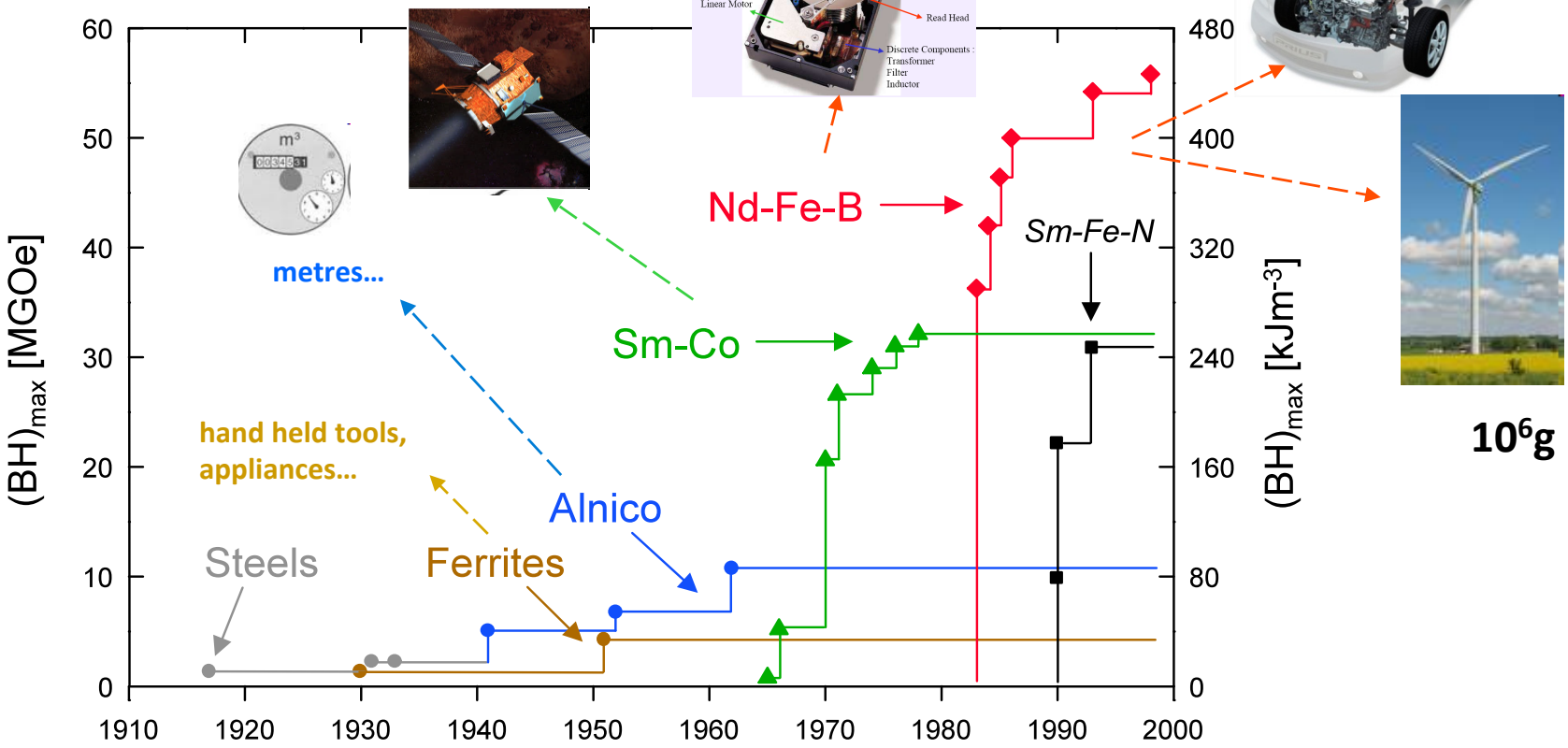
texture, non-magnetic 2^y phases

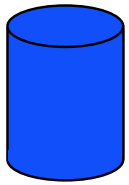
$(BH)_{max}$: Energy density

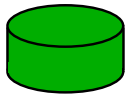
Work which can be done by magnet

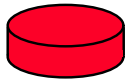
Improving the $(BH)_{max}$ of magnets.....









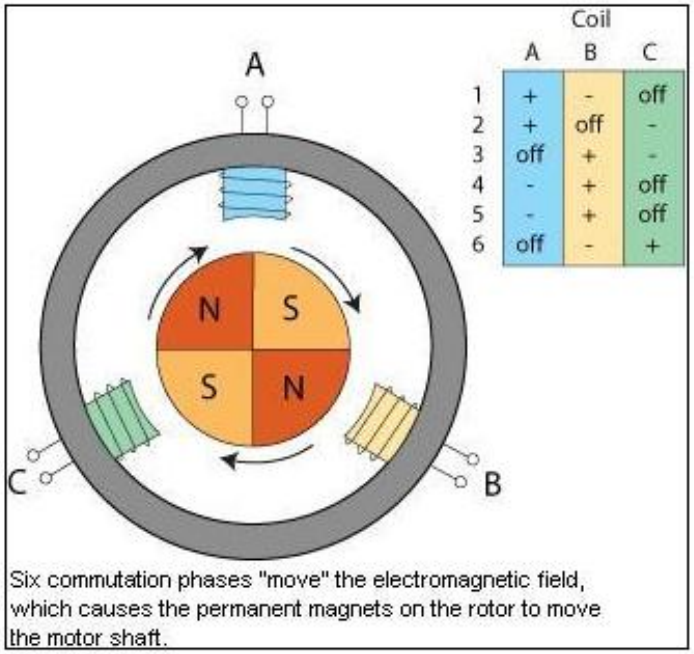


↑$(BH)_{max}$ →
↓ magnet volume

when Hc large
$(BH)_{max} \propto M_r^2$

Improved Magnets → Improved Motors / Generators

Development of high performance RE-TM magnets led to the emergence of Brush Less DC motors



Six commutation phases "move" the electromagnetic field, which causes the permanent magnets on the rotor to move the motor shaft.

Advantages of Brush Less DC motors

w.r.t. brushed DC motors, induction motors:

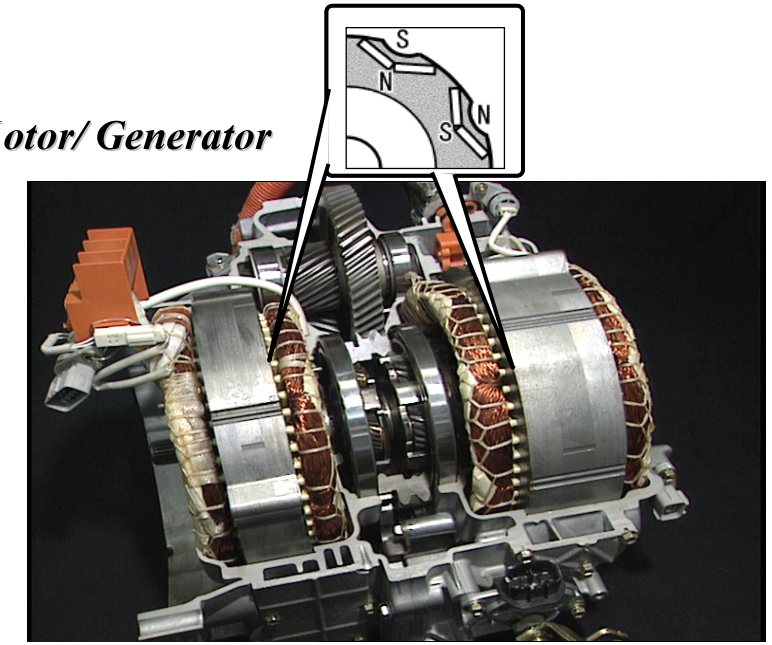
- **more torque per weight / power / efficiency / reliability**
- **maintenance-free operation**
- longer lifetime (no brush and commutator erosion)
- elimination of ionizing sparks (operation in explosive environments)
- reduced noise
- BUT more expensive (electronic commutation systems, more complex design / fab…)

Magnets in (Hybrid) Electric Vehicles

Toyota Prius

~1.2 kg of NdFeB-based magnets / car

HV Motor/ Generator



HEV motors: NdFeB vs ferrites

More efficient + reduced weight !

NdFeB-based magnets for EV/HEV

Year	Ton
2000	10,000
2010	60,000
2020*	160,000

*** forecast**

Tetsuya Shoji & Hiroshi Okajima,
Toyota Motor Corporation

Magnets in direct drive wind turbines

Elimination of gearbox
→ **technological leap forward**

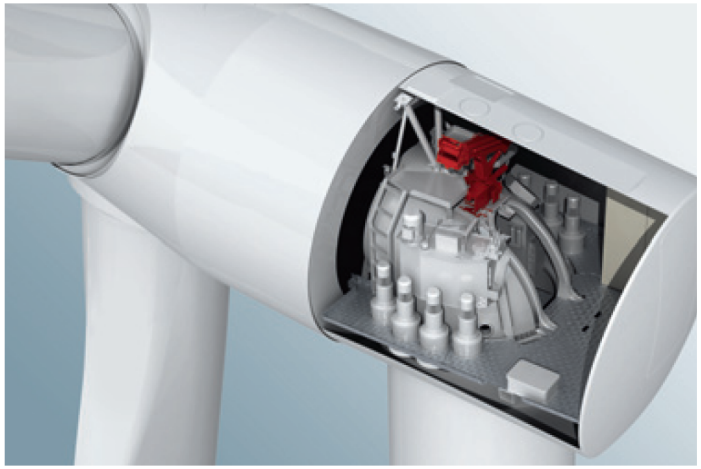
⇩

- reduced complexity

- increased efficiency

- increased reliability
(**reduced maintenance cost / service time**)

-compact design
(cost effective transportation / installation)



3 MW turbine = 2000 kg NdFeB

Magnetic Micro-systems for Energy

O. Cugat

μ-systems may be used to improve energy efficieny in macro-systems (cars, houses…)

μ-energy harvestors for low power applications, e.g. sensors, nomadic devices…..

Smart houses need networks of sensors, to control heating, lighting needs…

Exploit changes in T, σ, H

Soft magnets
Hard magnets
Magneto-caloric
Magnetostrictive
Magnetic shape memory

Composite structures: e.g. magnetoelastic + piezo

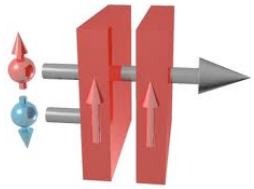
« Spintronics »

information/communication related technologies (data storage, processing and transmission), ever-increasing energy demands……

Spintronics: spin dependence of the electrical conductivity of a ferromagnetic system

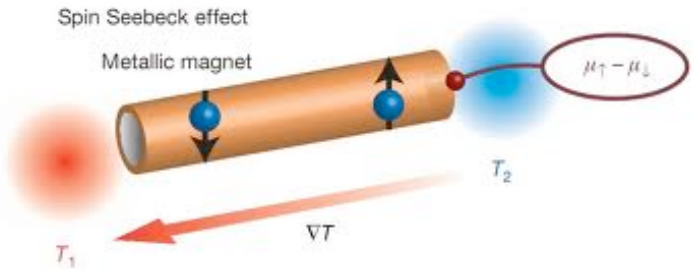
relative energy efficiency of magnetic devices
(e.g. non-volatile memories vs volatile memories)

M. Viret



Spincaloritronics: spin dependence of the thermoelectric properties of a ferromagnetic system
⇒charge current free generation of pure spin current,
more efficient control of the magnetization

S.O. Valenzuela

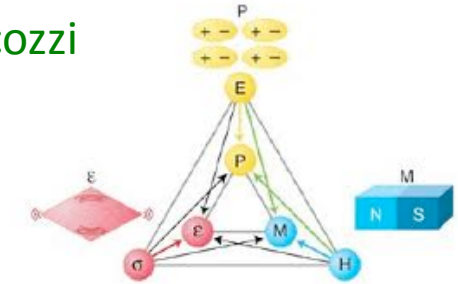


Multiferroics: more than one long-range order: ferro -magnetism, -electricity, -elasticity

S. Picozzi

Magnetoelectrics: ferroelectric (magnetic) properties
controlled magnetic (electric) field

voltage control vs current control (reduced Joule losses…)



Spintronics: an industry viewpoint L. Lombard

Magnetism plays an important role in Energy Economics…

Already an essential element for electricity

Cleaner energy,

Increased energy efficient,

but ever increasing energy use….