Superconductors for efficient and robust hybrid storage systems

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COST action MP1004 & XERMAE

Where we are?


Ireland
Nederland
Berlin
Polska (Poland)
Беларусь (Belarus)
London
Deutschland (Germany)
Paris
France
Україна (Ukraine)
Казахстан (Kazakhstan)
Монгол Улс (Mongolia)
România (Romania)
Italia (Italy)
Marseille
Barcelona
Black Sea
Caspian Sea
Portugal
España (Spain)
Lisboa
Roma
България (Bulgaria)
Türkiye (Turkey)
Türkmenistan (Turkmenistan)
O'zbekiston (Uzbekistan)
Mediterranean Sea
Beijing
中国 (China)
Persian Gulf
Bhutan
Cerdanyola del Vallès
Montcada i Reixac
Sant Cugat del Vallès
Santa Coloma de Gramenet
Horta-Guinardó
Sarrià-Sant Gervasi
L'Eixample
Barcelona
L'Hospitalet de Llobregat
El Prat de Llobregat
Universitat Autònoma
Institut de Ciència de Materials de Barcelona
Institut Català de Nanotecnologia
Escola Tècnica Superior d'Enginyeria
Autopista del Mediterrani

Who we are?

The institute

Nearly 200 wise Scientists trying to develop, understand, and optimize functional materials . A part, for energy applications

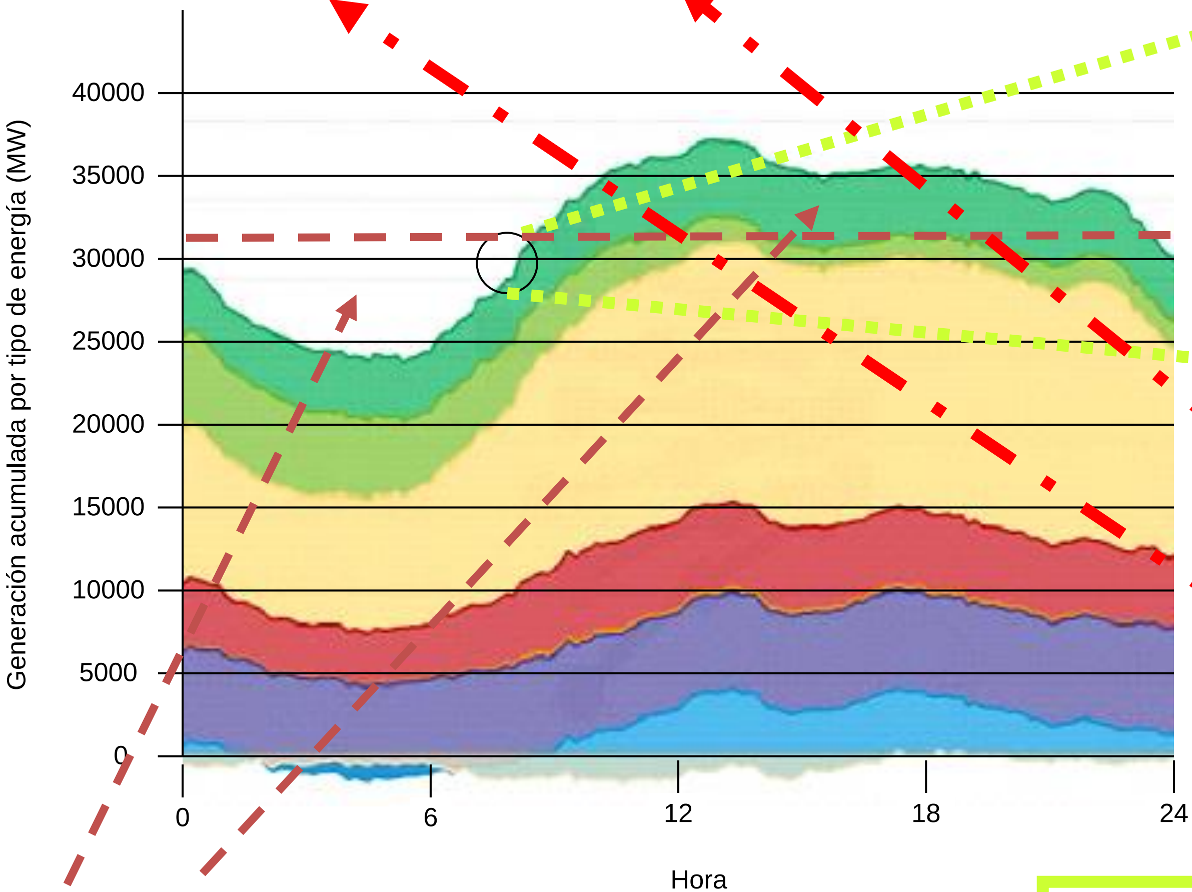
Our Department

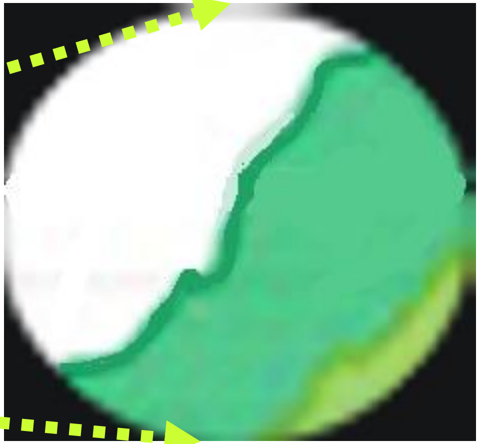
Superconducting materials: The materials, Their Physics and their Applications . From nanoscale to kilometers

Grid Storage Requirements: Quality and efficiency

Electric grid is not able to store energy

Demand = Generation





Renewals introduce sudden changes on Generation.

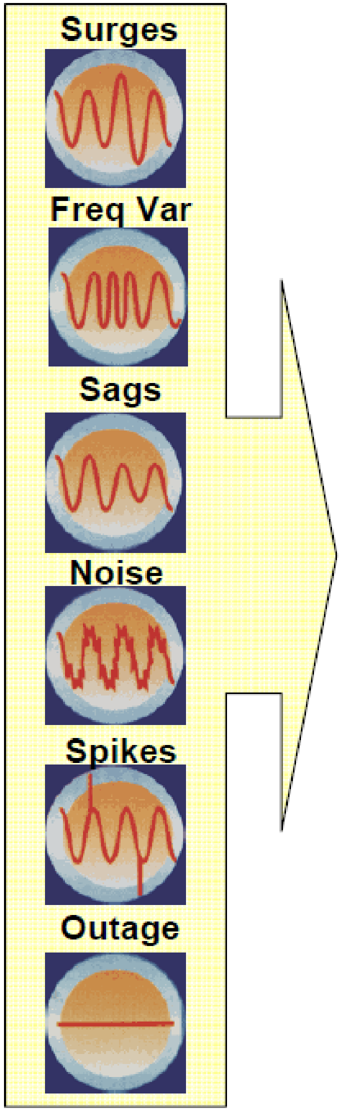
Generation should change in short time according to sudden changes of Demand.

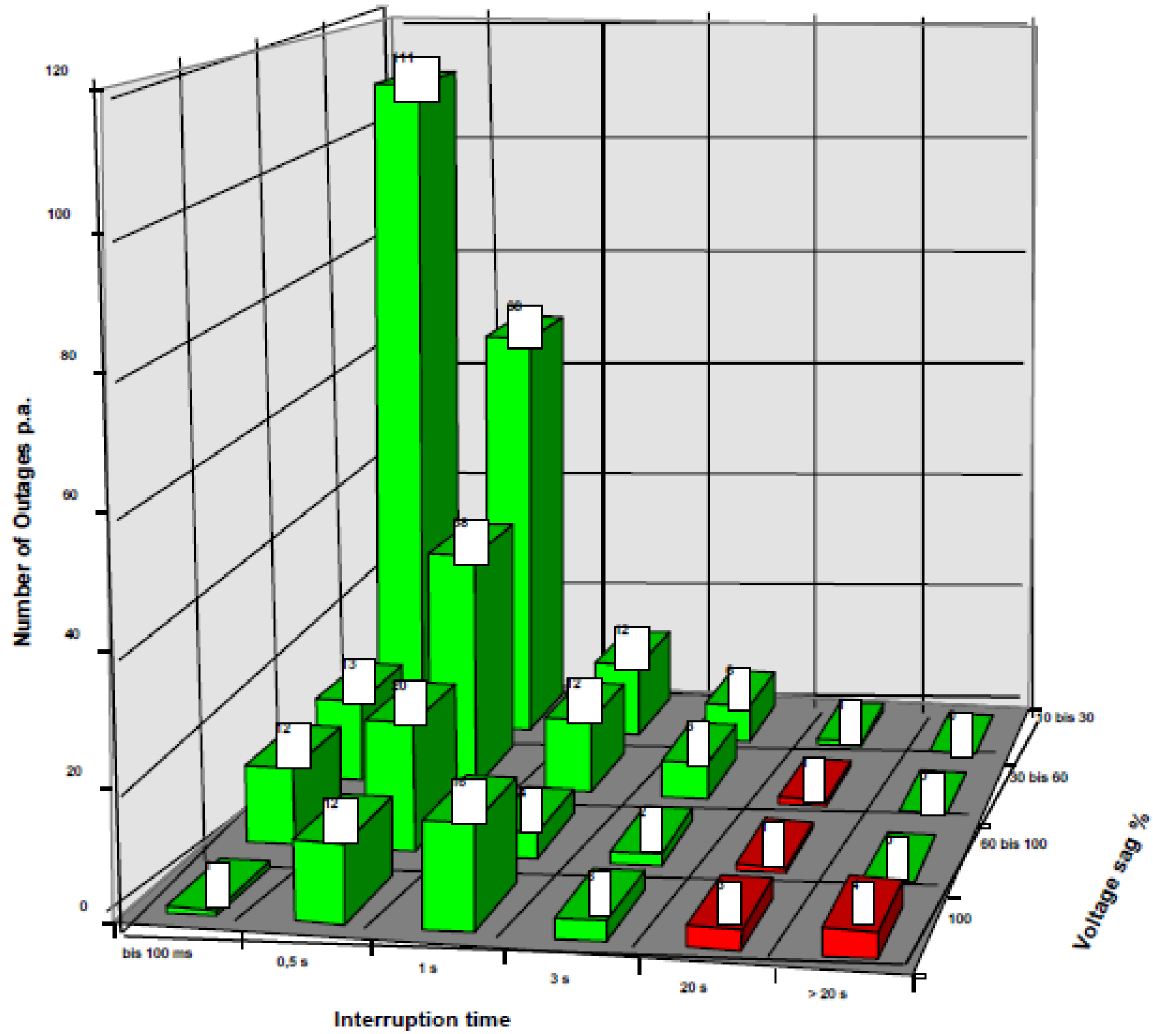
Frequency loss can occur!

Long term High Energy Storage systems improve the efficiency and the capacity of the grid

Long life low energy and high power Storage systems must be installed in the grid

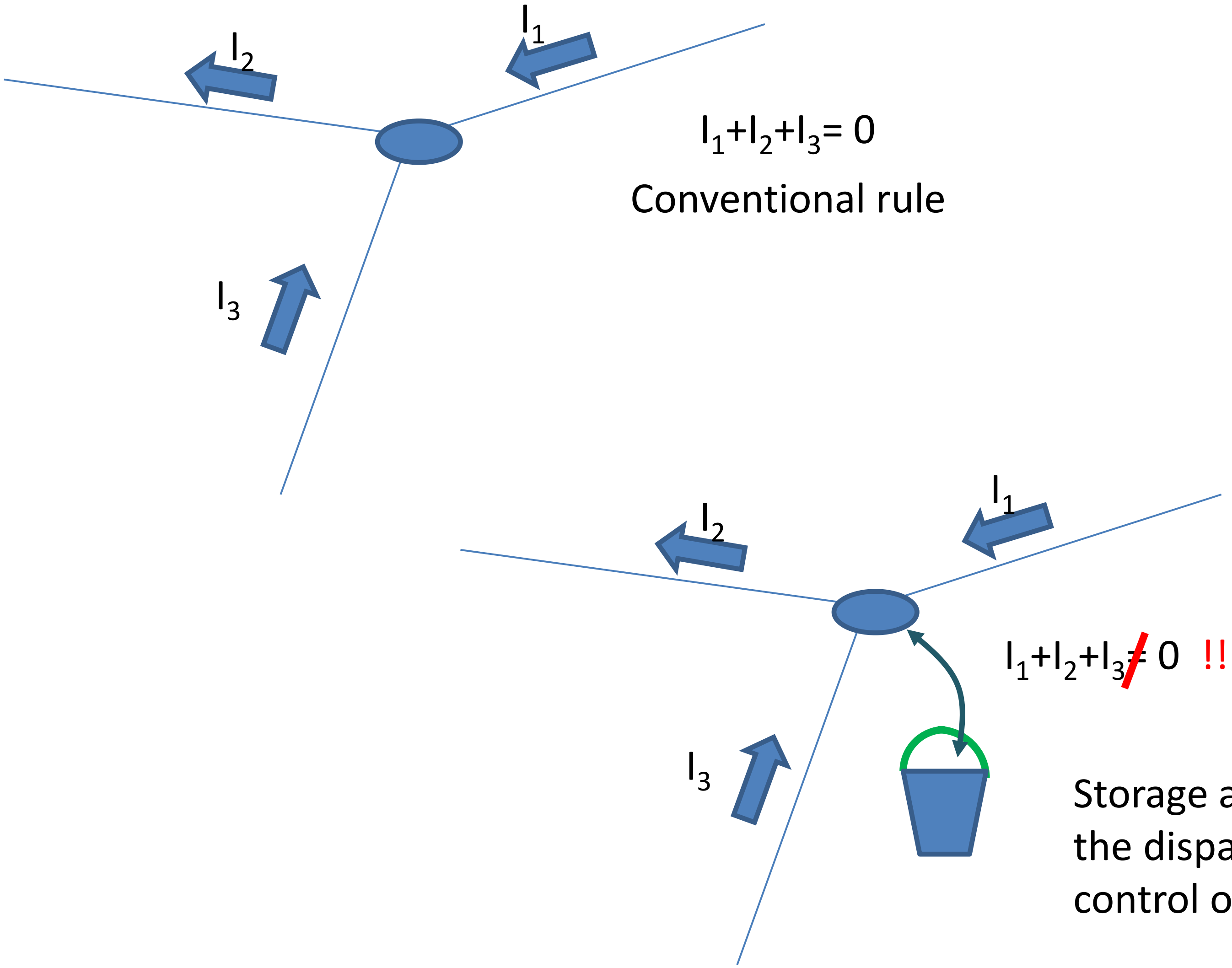
Grid Storage Requirements: Quality





Harmonics too!

Grid Storage Requirements: dispatching



$I_1+I_2+I_3= 0$

Conventional rule

$I_1+I_2+I_3 \neq 0$!!!

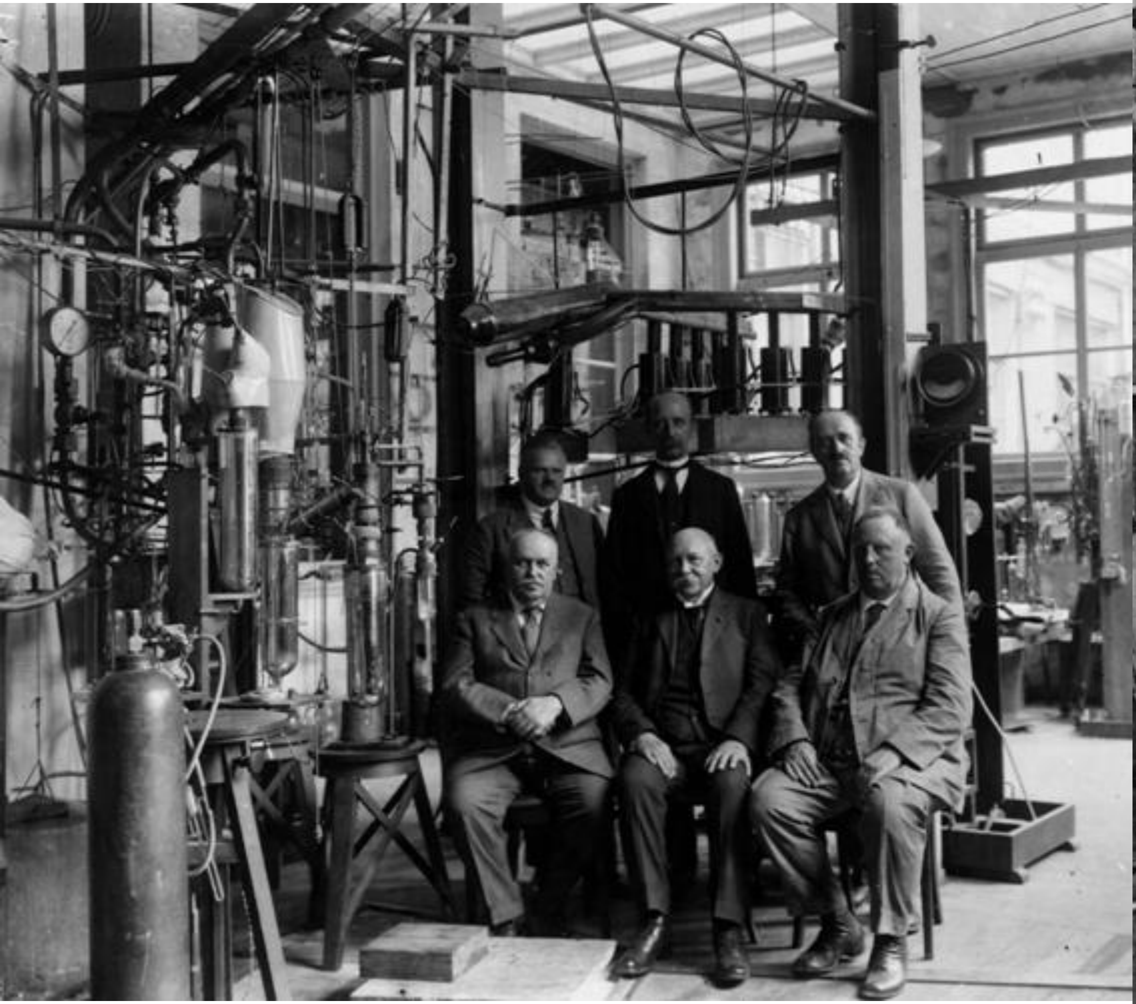
Storage allows flexibility in the dispatching and better control of the energy flow

Available Technologies

discharge time / Type of Energy	Short Sec .. min	medium min .. hrs	long hrs ..day
electrical	Capacitor Supercapacitor		
magnetical	SMES		
thermic			Hot water, hot steam, molten Salt Solid body storage (Cowper storage, rock, concrete etc.)
potential	Spring Storage[1)]	CAES & ACAES & LAES	CAES & ACAES & LAES + PUMPED HYDRO
kinetic	FLYWHEEL		
chemical		H_2 tank+fuelcell, fossile fuel tank + thermal energy converter (ICE, Gas Turbine..) Chem. batteries (PB-, NiCd-, Li-Ion, VaRedoxFlow, NaS)	

W.R Canders IEMAB

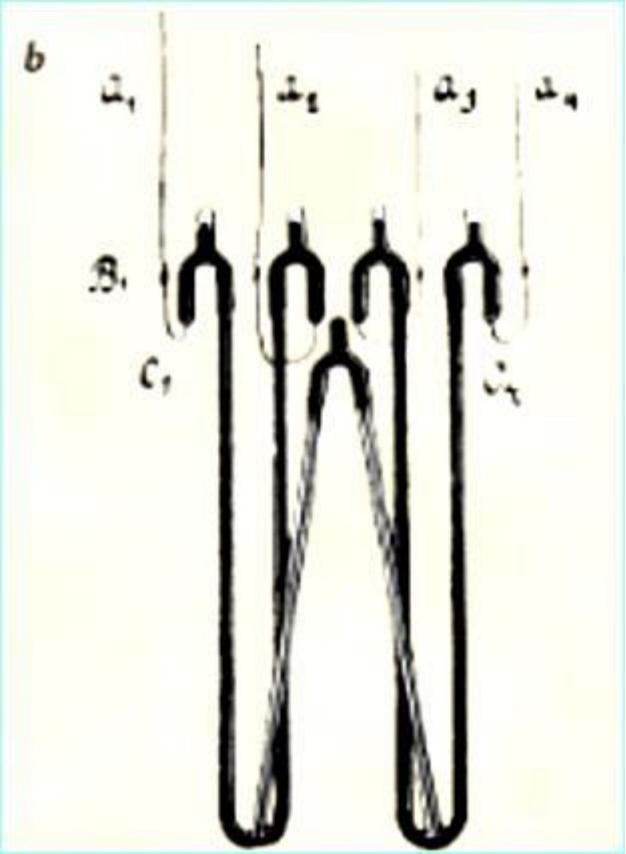
Kamerlin Onnes Laboratory

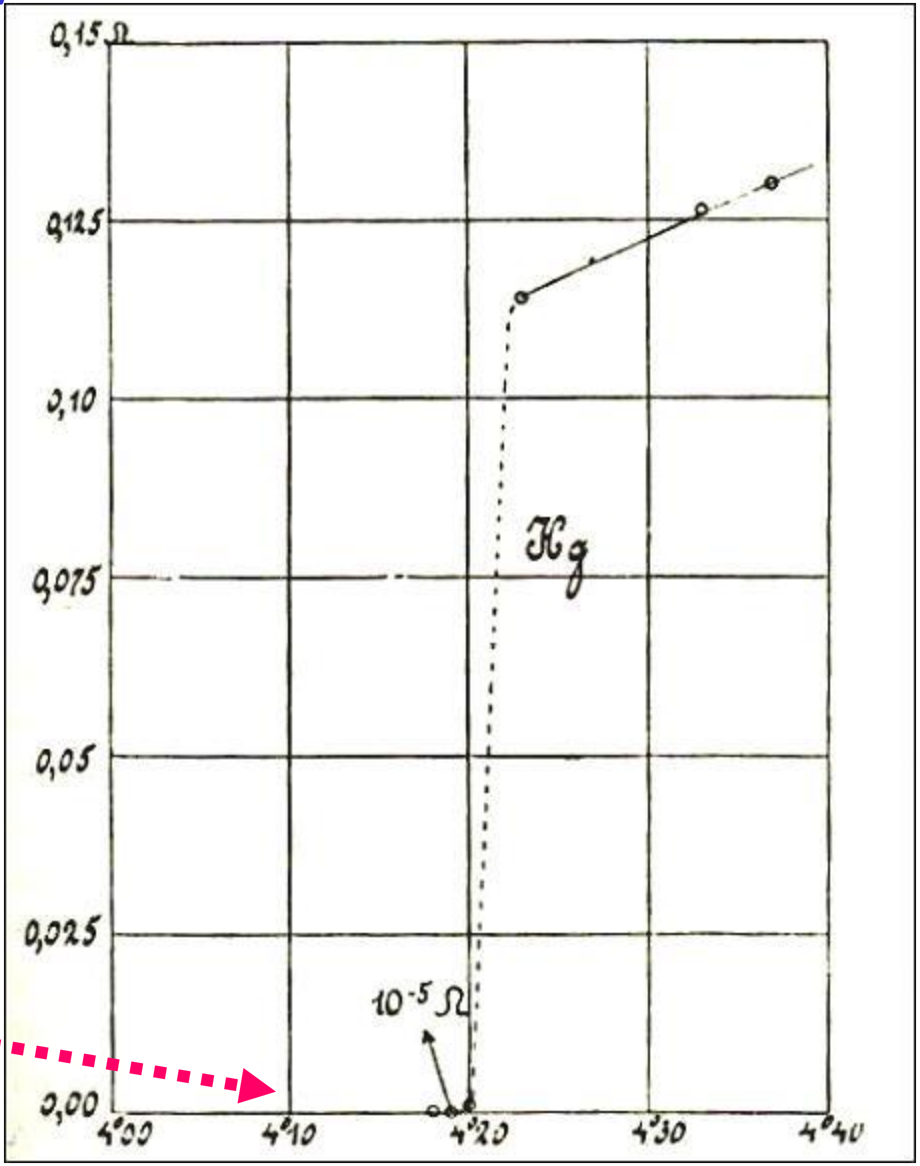


July, 10th 1908 Helium is liquidized
Leiden becomes the coldest point of the earth

A crucial experiment

Mercury resistivity : 1911





Is a "superconductor"

Basic Properties

Macroscopic

No resistance

Diamagnetism

Magnetic Flux Pinning

Electro-technical Applications level

Microscopic

Electronic interactions.

Vortex dynamics & other Micro-nanoscopic effects

Sensors (SQUID) (transition edge)

Superconducting electronic Devices

Microwaves
ETC.

Superconductors should be cooled

System engineering : cryogenics

LTC materials

HTS materials

Liquid gases: He (4’2K), H_2 , Ne, **N_2 (77K),** Ar

High cost (6 euro/lit)
(Limited reserves)

Low cost (0’64 euro/lit)
(Abundant)

Cryocoolers
Low maintenance cost
Long time between maintenance operations (in the range of 10 years)
Thermodynamic expansion cycles with He, Ne, H_2 , mixed gases
JT, GM, Stirling, **Brayton (Maitainance free!)**

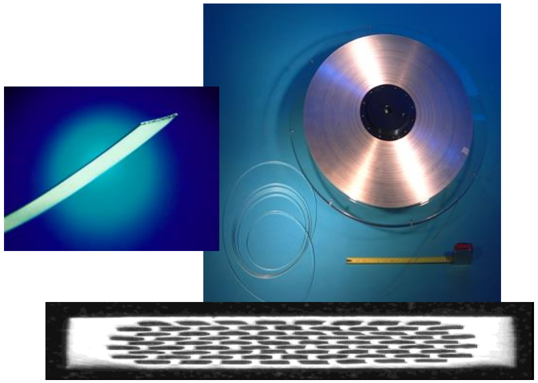
Lower efficiency ←

→ Higher efficiency

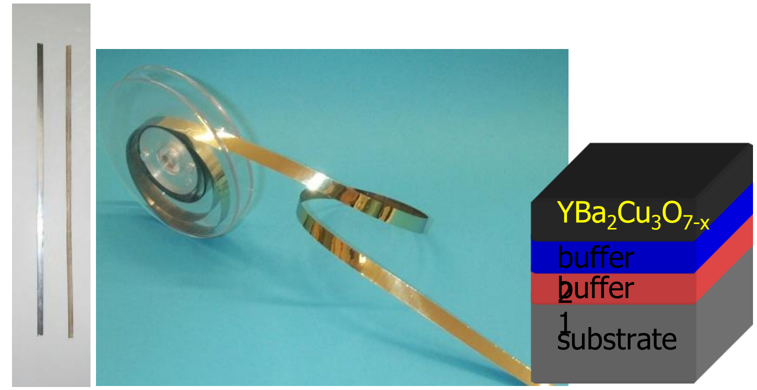
Low temperature: higher cost

High temperature: lower cost

HTS comercial materials

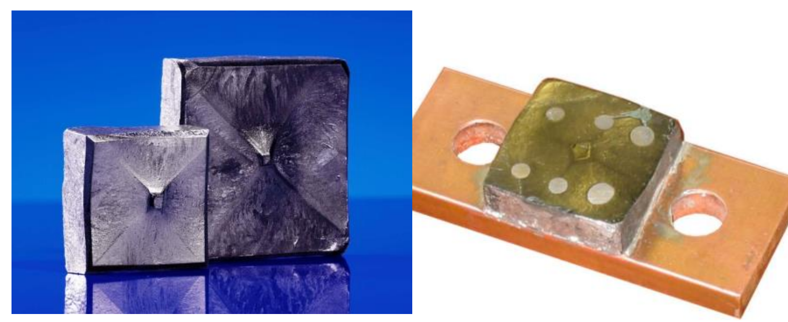


Bi-2212/ Bi-2223 Tape
1rst generation



Y-123 cc-tape
2ond generation

Bi-2212 bulk



Y-123 bulk

300€/pellet

HTS electrotechnical applications

- Improvement of conventional devices
- New functions, new devices

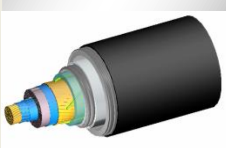
➢COST Cryogenics+ material+ installation

Less weight & volume → Higher power density
Losses reduction → Higher efficiency

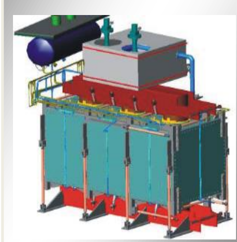
Improvement of convetional systems

New systems

Cable



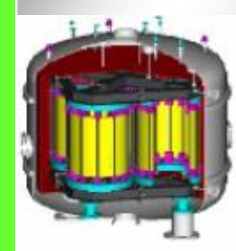
Trans-former



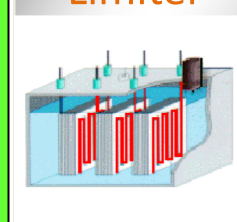
Motor Generator

Flywheel

SMES



Fault Current Limiter

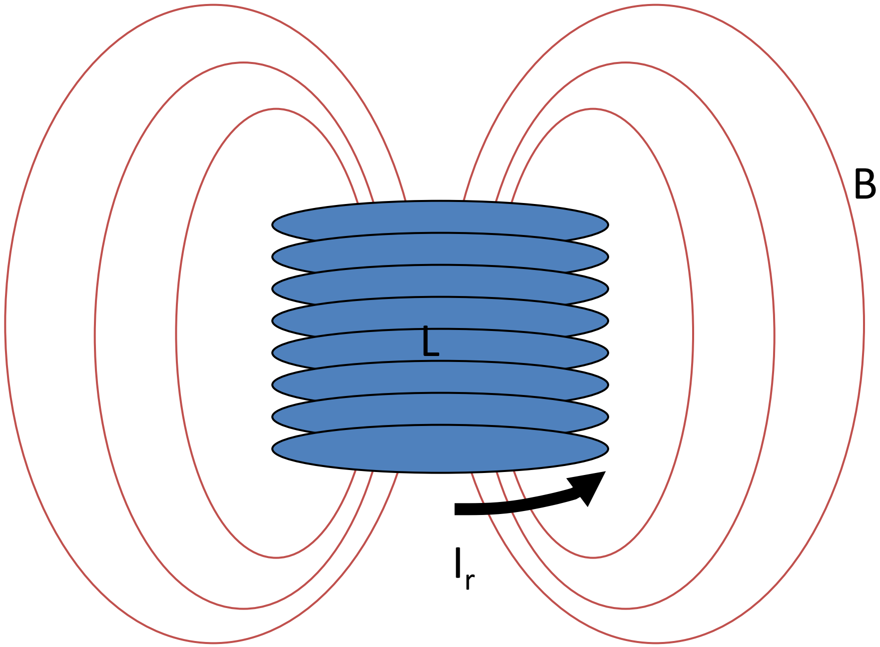


Cable	Transformer	Motor Generator	Flywheel	SMES	Fault Current Limiter
Higher Power Density Retrofit	Energy Savings Environmental Safety Mobile Transf.!	Volume, Weight, Energy savings	Energy Density Energy Savings Safety	Availability Savings of Resources	Novel Power Grids Power Quality Savings of Ressources

Electric Energy Storage:

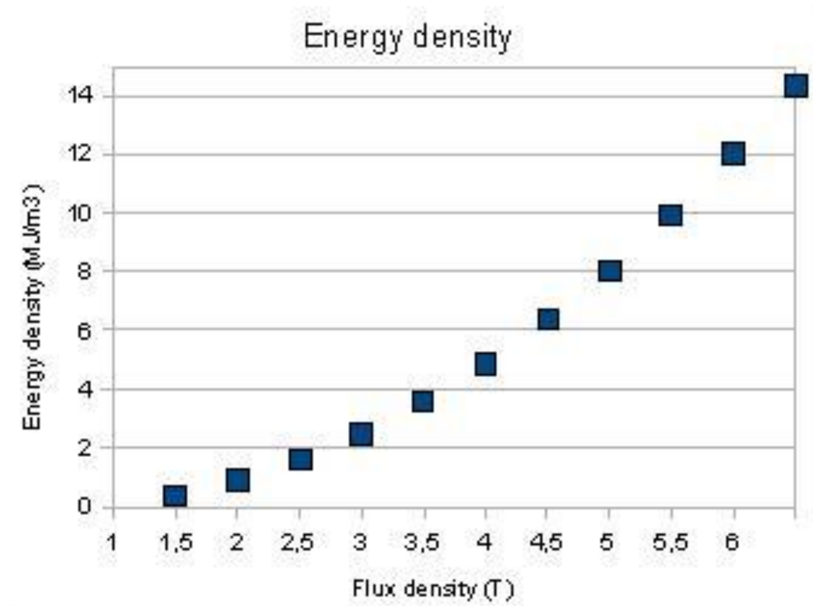
What superconductivity can do for?

Magnetic Field Energy



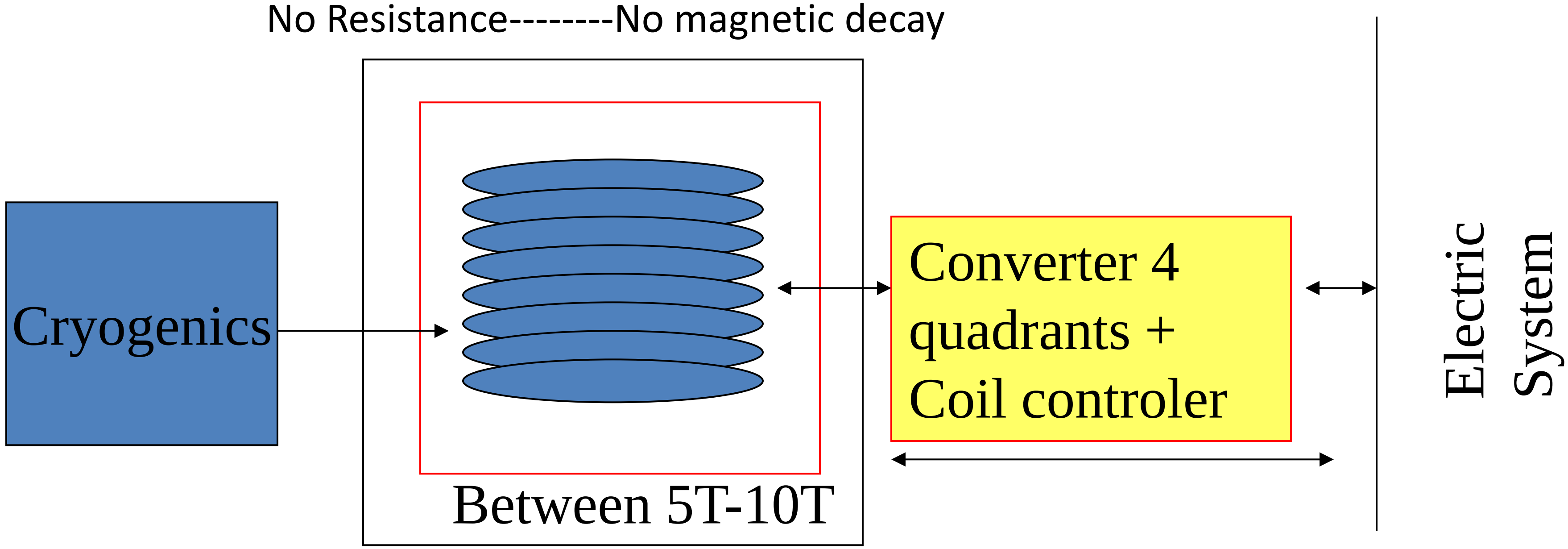
$$Q_{max} = \frac{1}{2} L_s I_r^2 = \int_v \frac{B^2(v)}{2\mu_0} dv$$

Each cubic meter of magnetic field at 1T stores de same energy than that of a cubic meter of water at 40m. At 6T, the energy density of stored magnetic field is 36 times higher.



Superconducting Magnetic Energy Storage

No Resistance--------No magnetic decay



$$Q_{\max} = \frac{1}{2} L_s I_r^2 = \int_v \frac{B^2(v)}{2\mu_0} dv$$

Between 10 y

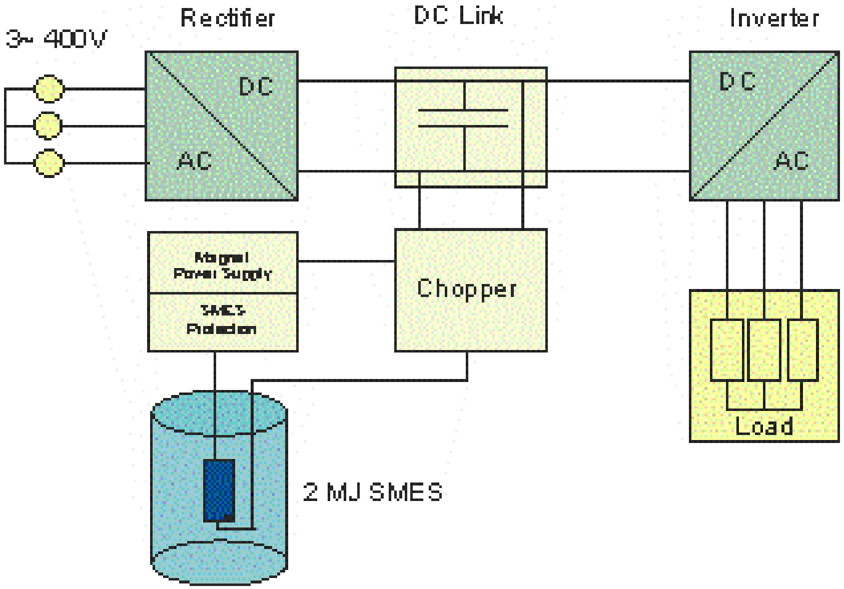
40MJ/m^3

Maximum power:
Limited by $V_{\max}$
(electronics & isolation)
and losses

Very high efficiency, nearly 90-95% (depending on the storing time)
Unlimited cycling

Status:
Low Temp---------- commercial
HTS------------------ development

S M E S: LT Comercial devices



Max current	1000 A
Max energy	2.1 MJ
Average power	200 kW
Max power	800 kW
Voltage DC max	800 V
Ma flux density	4.5 T
Self Inductance	4.1 H
Diameter	760 mm
Highness	600 mm

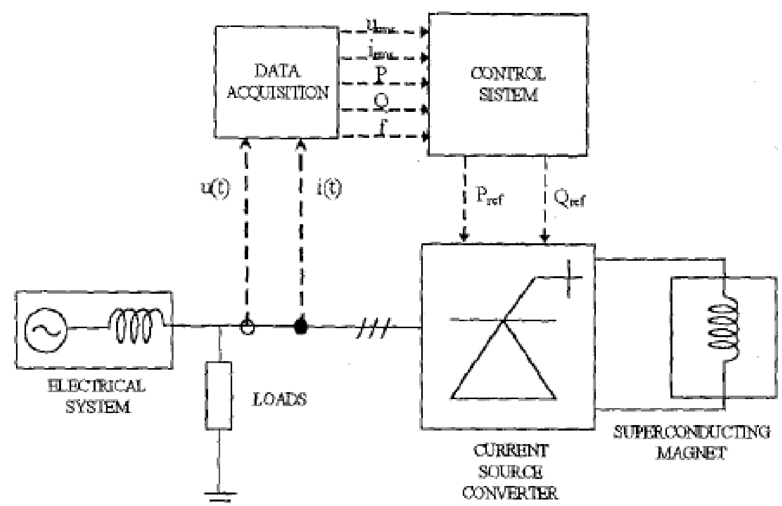
S M E S: LT SMES

AMAS-500 project (1994-1996).Two LTSC SMES, 25kJ, 50KVA & 1MJ- 1MVA (coord: ASINEL & IBERDROLA)

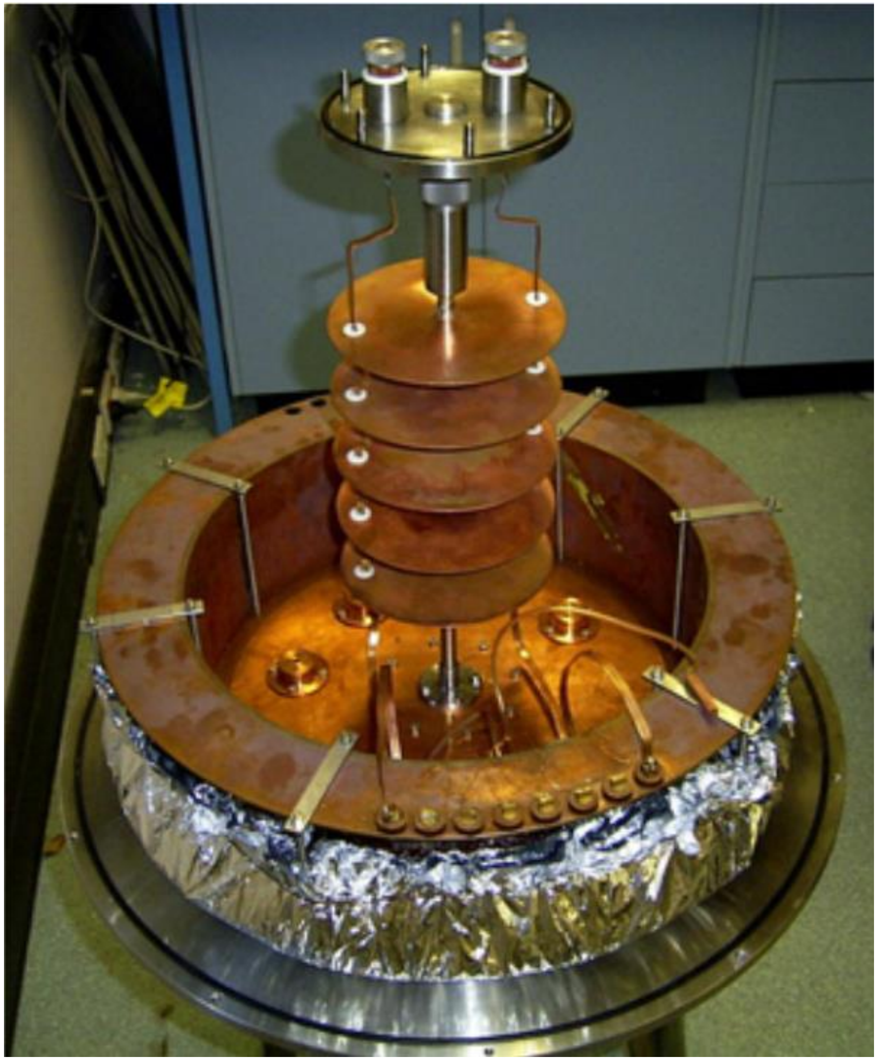
LT Supercoductor: NbTi

SMES PROTOTYPE CHARACTERISTICS

Parameter	
Stored Energy	25 kJ
Rated Current	115 A
Self-Inductance	3.8 H
Rated Voltage	500 Vdc
Rated Power	50 kVA
dI/dt	131 A/s
Converter Topology	CSI 6-pulse
Semiconductor devices	GTO
Firing Strategy	Optimal PWM
Control	Multilevel adjustable PID
Auxiliary circuits	Quench protection
	Energy maintenance



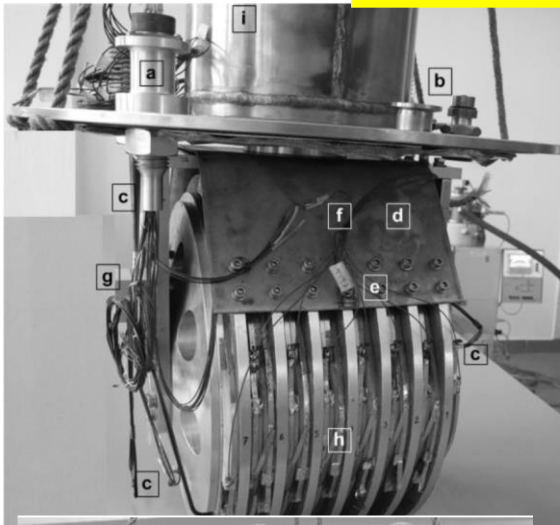
HTS SMES



Bobina de SMES
SC SuperpowerSystems Australia
HTS Material BSCCO 2223

Parameter	Value	Parameter	Value
Inner Diameter	0.380 m	Critical Current in Field at 25K	140 A
Outer Diameter	0.436 m	Maximum Perpendicular Field	695 mT
Height	0.116 m	Inductance	0.285 H
Tape Length	2000 m	Energy Stored	2.79 kJ

HTS SMES



Electrotechnical Institute in Warsaw

BSCCO 2223

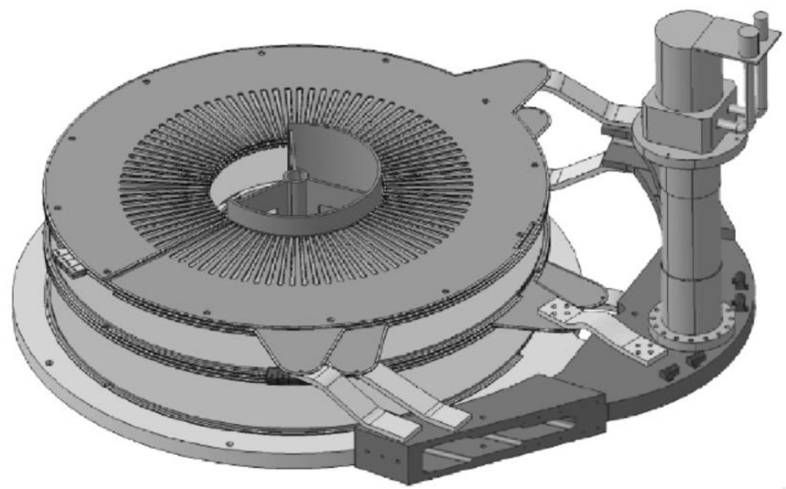
Temperature (K)	Max. Current (A)	Max. stored energy (kJ)
77	25	0.31
64	50	1.25
35	180	16.20
13	264	34.80

Parameter	Value
Inner diameter of coil	210 mm
Outer diameter of coil	310 mm
Distance between coils	8.6 mm
Number of coils / pancakes	14
Number of double-pancake coils	7
Height of magnet	191 mm
Weight of magnet	53 kg
Length of HTS tape in the magnet	1621 m
Width / thickness of HTS tape	4.2 mm / 0.31 mm
Critical current of HTS tape at 77 K	125 A

Journal of Physics: Conference Series 234 (2010) 032034

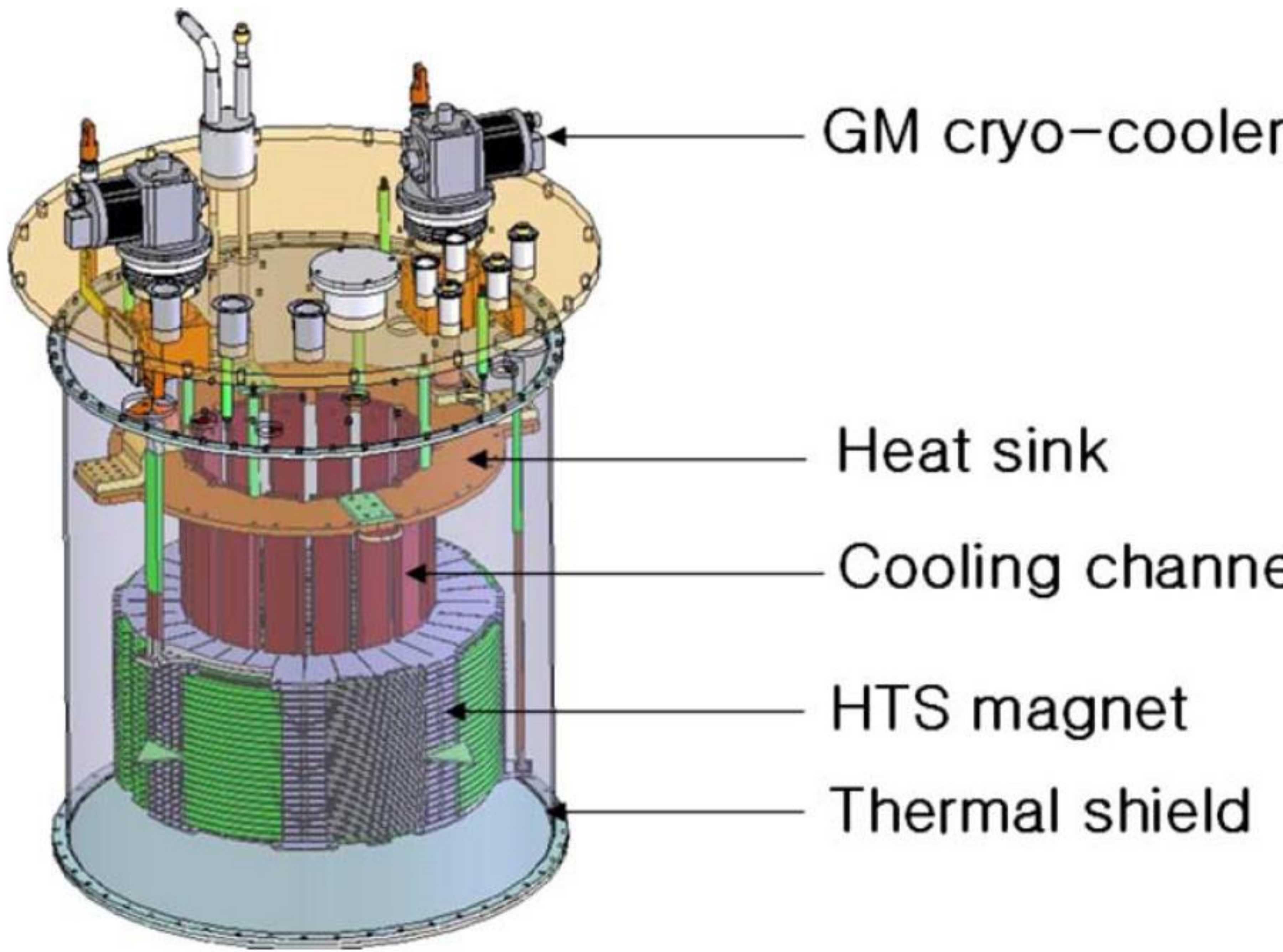
HTS SMES: for military applications

BSCCO 2212



Quantity	Value
Stored energy	814 kJ
Internal / External coil diameter - Height	300 mm / 814 mm – 222 mm
Rated current	315 A
Operating temperature	20 K
Number of pancakes	26
Max magnetic flux density (long/trans)	5.2 T / 2.5 T
Max circumferential stress / axial stress	80 MPa / 24 MPa

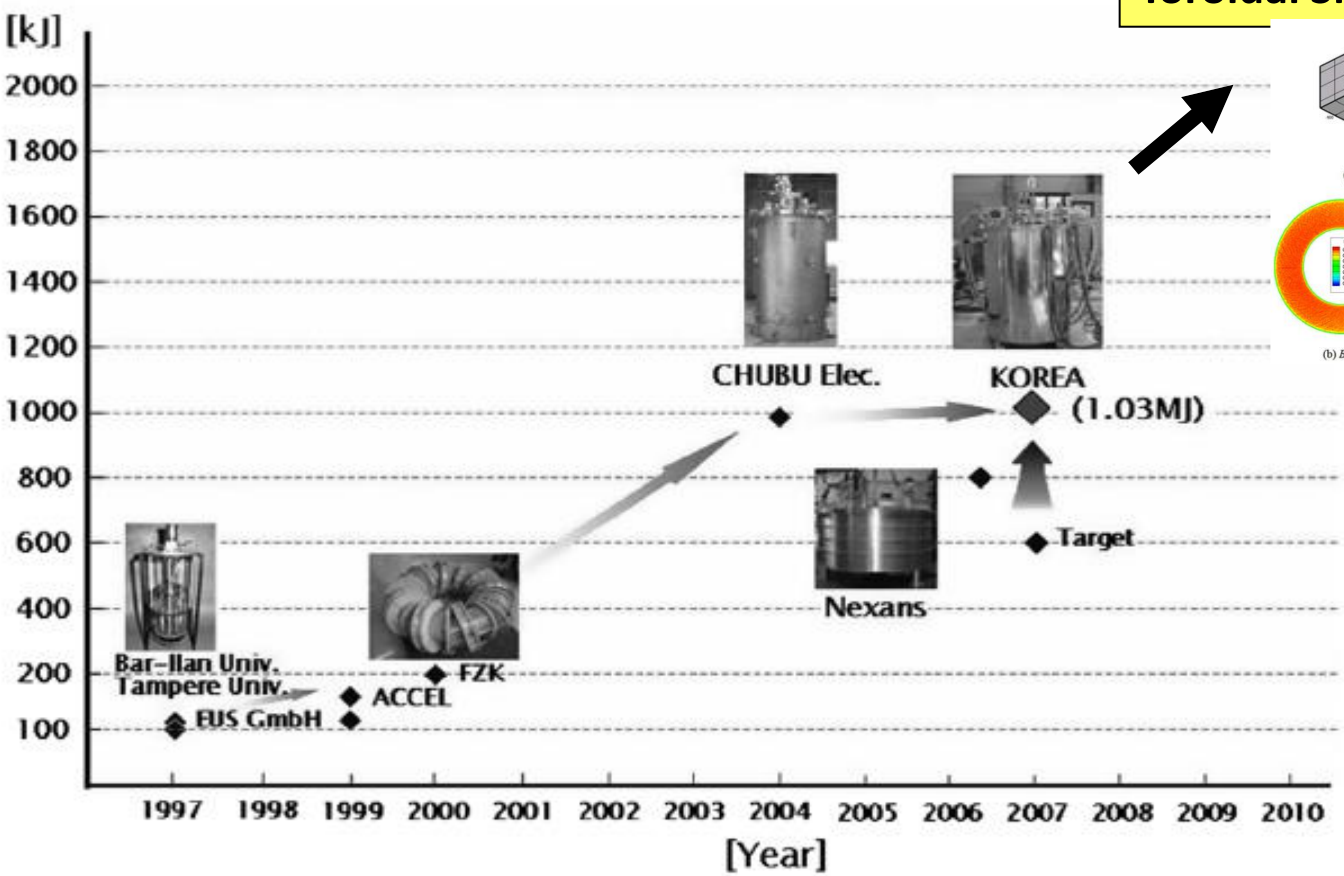
P. Tixador et al Cryogenics *arxiv.org/pdf/0812.3639*

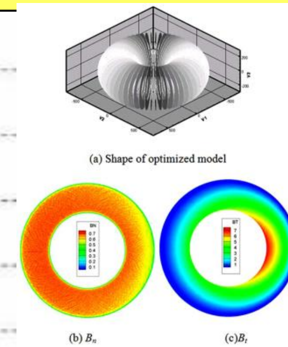


GM cryo-cooler
Heat sink
Cooling channe
HTS magnet
Thermal shield

S M E S: HTS development

New 2.5 MJ HTS Toroidal SMES

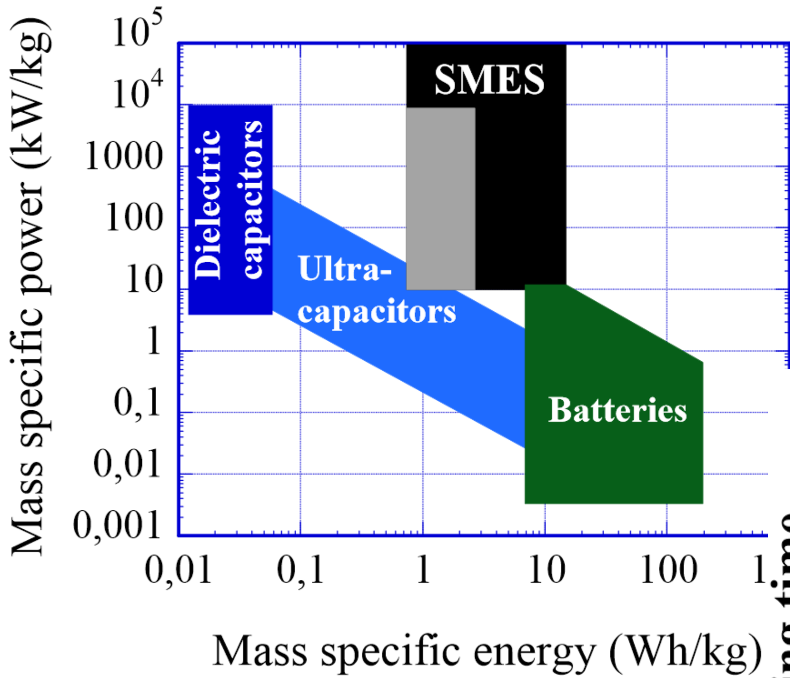




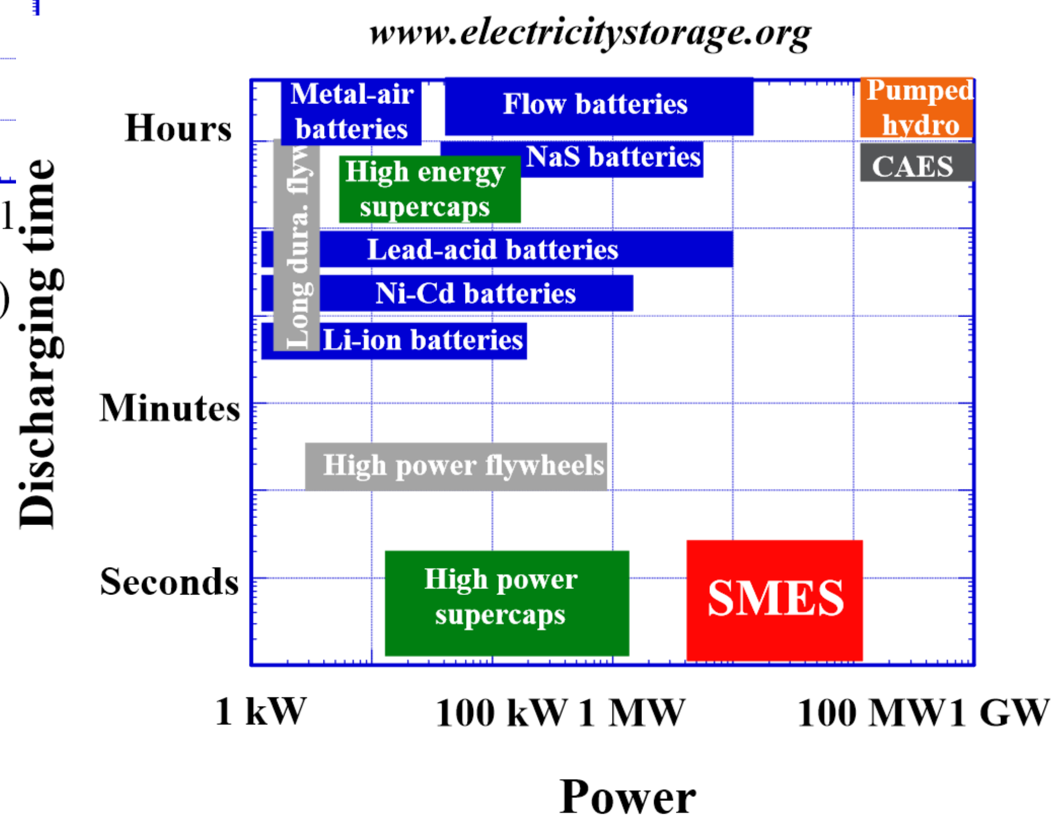
Korea

- Up to1GVA systems which can be used for load leveling, being in competence with water pumped plants.
- Up to 200 MVA range SMES, useful for frequency compensation in transmission lines 0.5-10 MVA which can support critical loads against dips, sags, momentary outages.
- The new topology of the grid, which includes micro-grids concept, requires a great number of this kind of robust and low cost storage systems in a lower range of power, less than 100KJ.

S M E S:

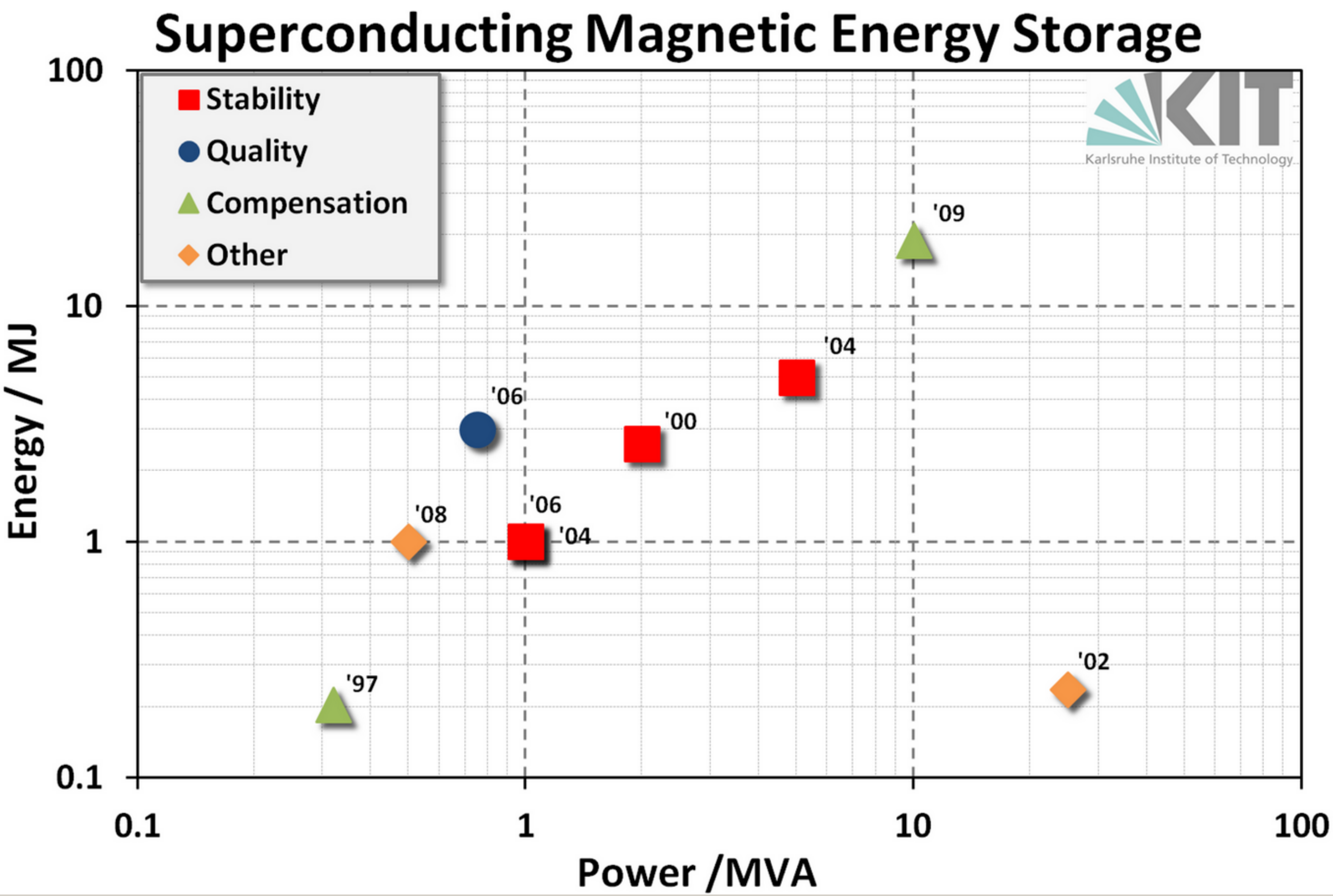


Mass specific power (kW/kg)
10^5
10^4
1000
100
10
1
0,1
0,01
0,001
0,01
0,1
1
10
100
1
Mass specific energy (Wh/kg)
SMES
Dielectric capacitors
Ultra-capacitors
Batteries



www.electricitystorage.org
Discharging time
Hours
Minutes
Seconds
Metal-air batteries
Flow batteries
Pumped hydro
NaS batteries
CAES
High energy supercaps
Long dura. flyw
Lead-acid batteries
Ni-Cd batteries
Li-ion batteries
High power flywheels
High power supercaps
SMES
1 kW
100 kW
1 MW
100 MW
1 GW
Power

S M E S:



Superconducting Magnetic Energy Storage
Stability
Quality
Compensation
Other
Karlsruhe Institute of Technology
'09
'04
'06
'00
'08
'06
'04
'97
'02
100
10
1
0.1
Energy / MJ
0.1
1
10
100
Power /MVA

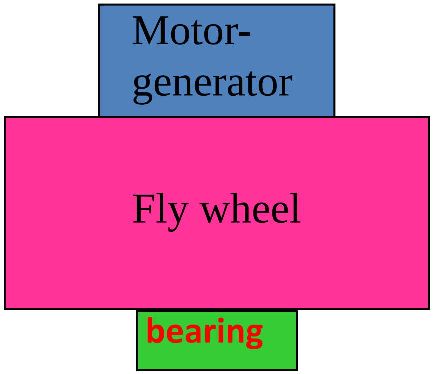
S M E S:

- Very Robust
- Efficient (>90% including cryogenics)
- High power Capability for short time
- Unlimited number of cycles
- Good Power & energy/mass, Power & energy/volume ratios

- Expensive

- Should be cooled

Flywheel Energy Storage



$$E = \tfrac{1}{2} I \omega^2$$

If geometry: hollow thin cylinder

$$E/m = \tfrac{1}{2} (r\omega)^2$$

Max speed approx= sqrt(**σ/ρ**) → Centrifugal explosion

depending on the rotor shape factors

Int J. mech. Sci., Vol. 19, pp. 223-231

Front. Mech. Eng. China 2008, 3(3): 288–292

In general $E/m = K\, \sigma/\rho$

Friction motor

Also in F1 race cars

KERS

Thick Cylinder Ri/Ro=0.75

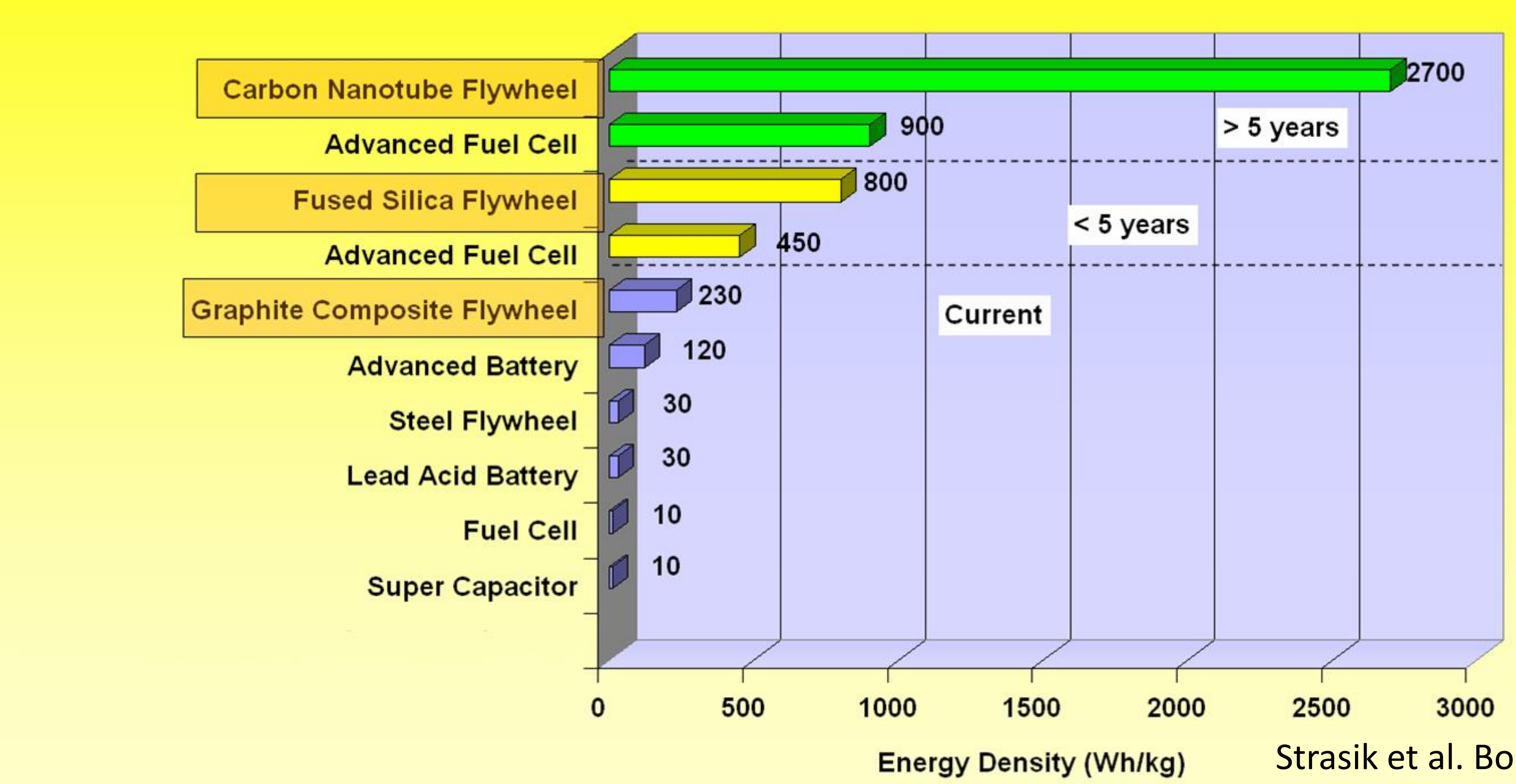
material	density ρ [kg/m³]	tensile strength σ[MPa]	rim speed v[m/s]	energy density E/m [Ws/kg]
steel	7830	1300	415	106
titanium	5100	1200	575	143
fib. glass	1900	1300	680	335
Graphite fiber	1546	6300	1570	1570

Journal of Physics: Conference Series 43 (2006) 1007–1010

Carbon nano tubes?	1300	Theoric: 300,000 Measured: 63,000 20mm Fabrics:3,600

Bearing: is an issue!

Energy Storage Systems



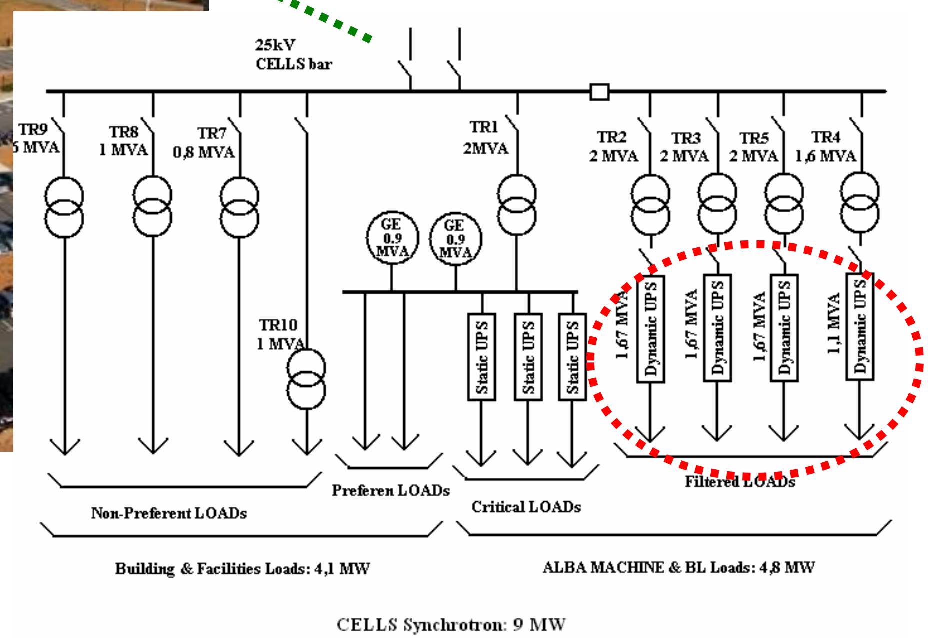
Strasik et al. Boei
ISS 2007

F E S UPS in ALBA Synchrotron

Magnetic Conventional Bearing

For UPS
(conventional PowerBridge)
3x 1.67 MVA Flywheels
1x 1.1 MVA Flywheel

Total 6.11MVA during 12s



M. Cusido, CELLS

Conventional MagLev F E S

SA²VE Project

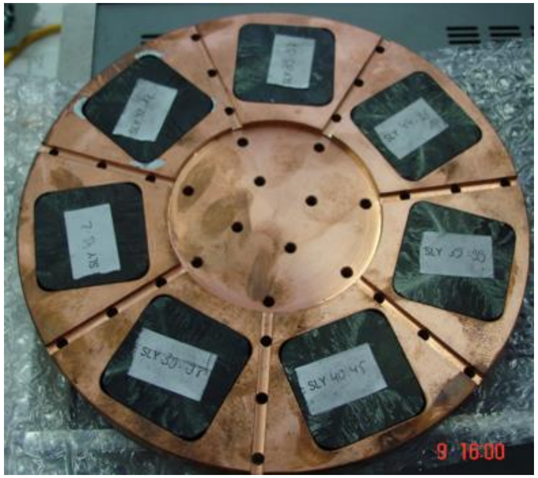
Tekniker-IK4
ADIF
CIEMAT
U. Sevilla
Zigor
Corporation Metro de Madrid
Elytt Energy
Green Power

Regenerative Braking
Railway application

First half of 2010 in Cerro Negro subestation (Madrid)

ICMAB CSIC Xarmae XARXA DE REFERENCIA EN MATERIALS AVANÇATS PER A L'ENERGIA

HTS MagLev



Cosmocaixa, Madrid, Barcelona

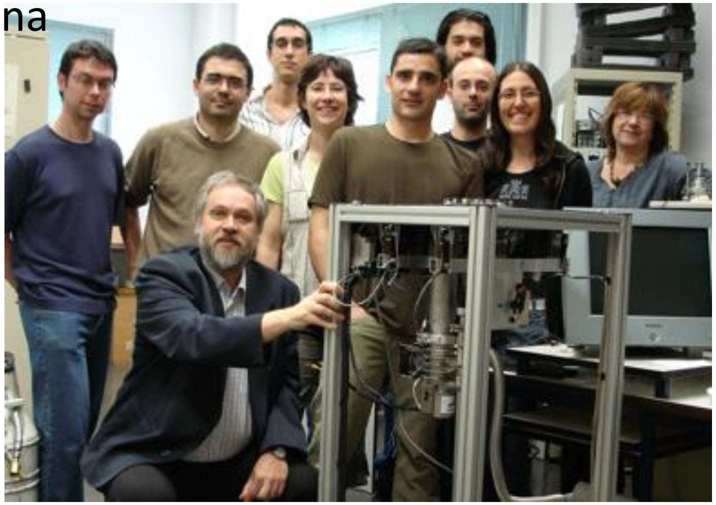
Temperatura ambiente

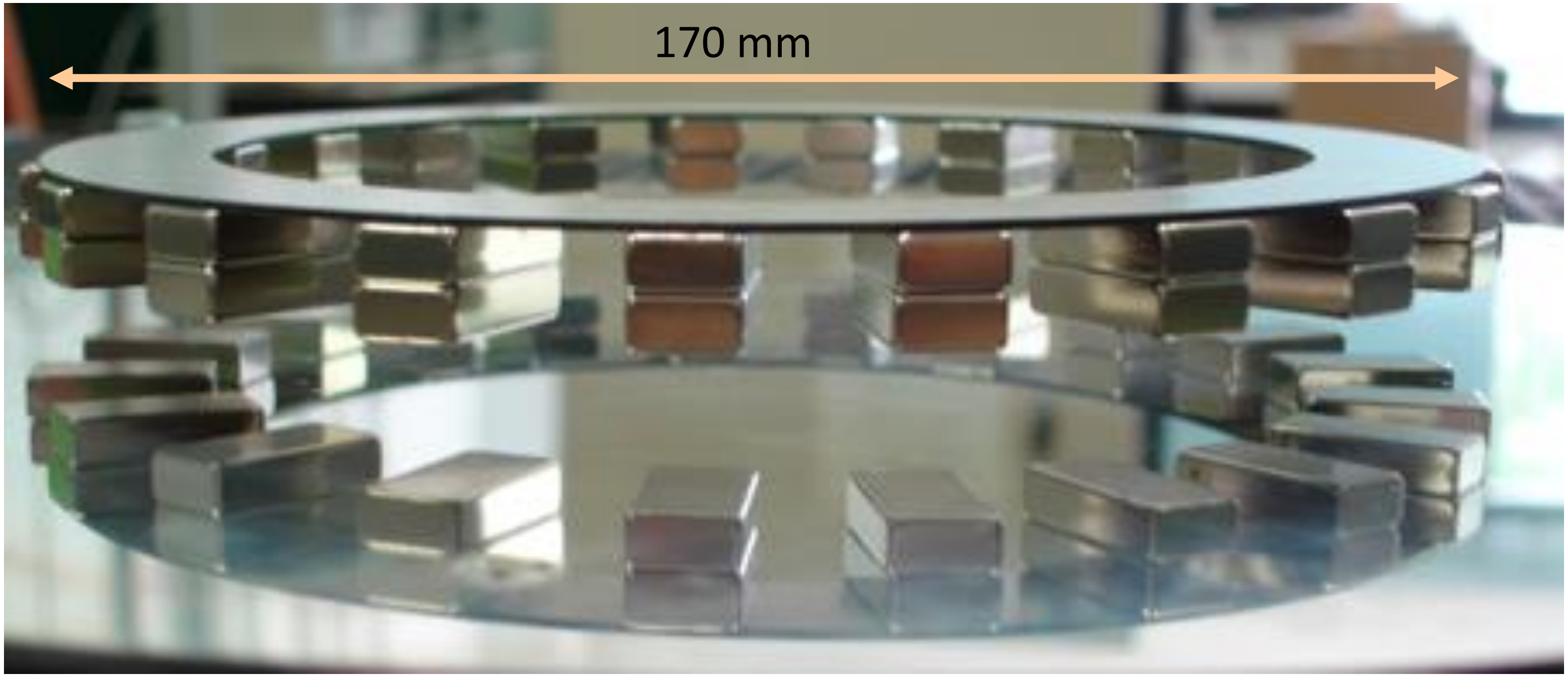
Sin deformación por compresión

Criogenerador integrado

2 años (tecnología comparada)

2 años (Abra Kadabra)

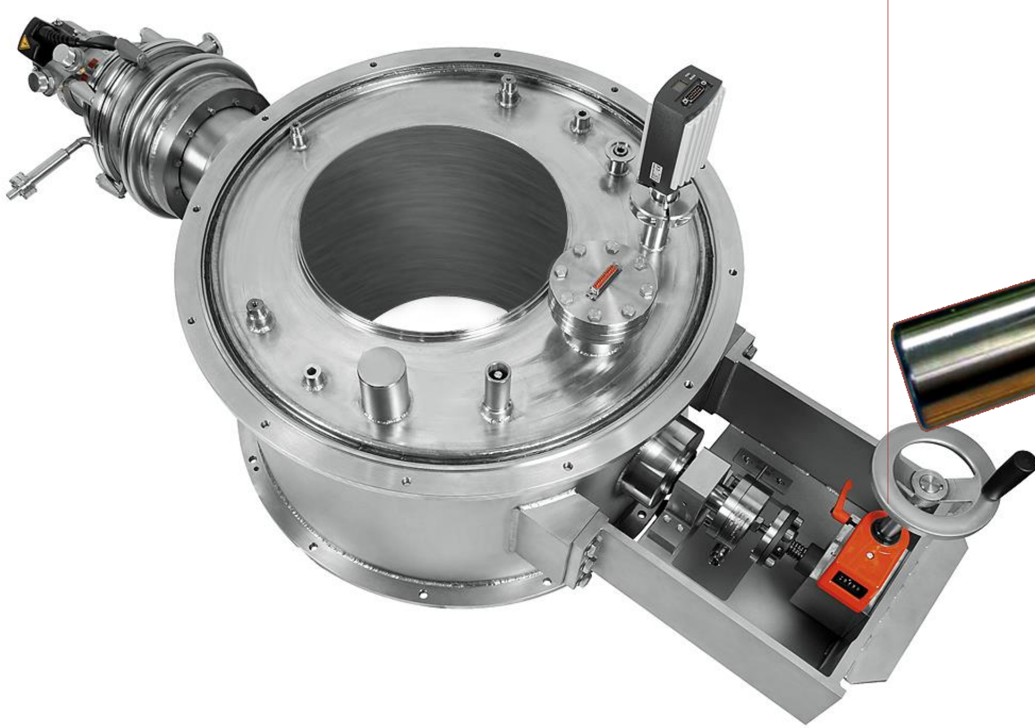




ICMAB CSIC Xarmae

HTS Bearing

First Heavy Load HTS Bearing for Industrial Application with shaft loads up to 10 kN



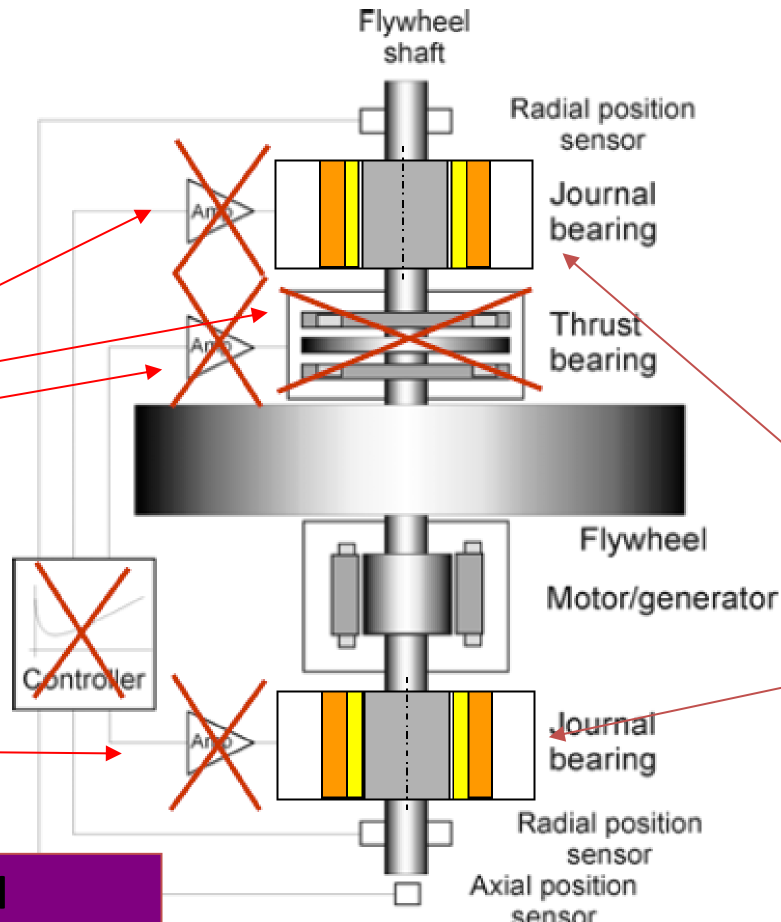
Rotor setup as collector array of NdFeB magnets stabilized by CFR-rings ($Ø_a$ 319 mm, L 305 mm)

World´s biggest HTS bearing

J. Boch Nexans Superconductors

Superconducting F E S

simplest (safest) way to keep a wheel spinning

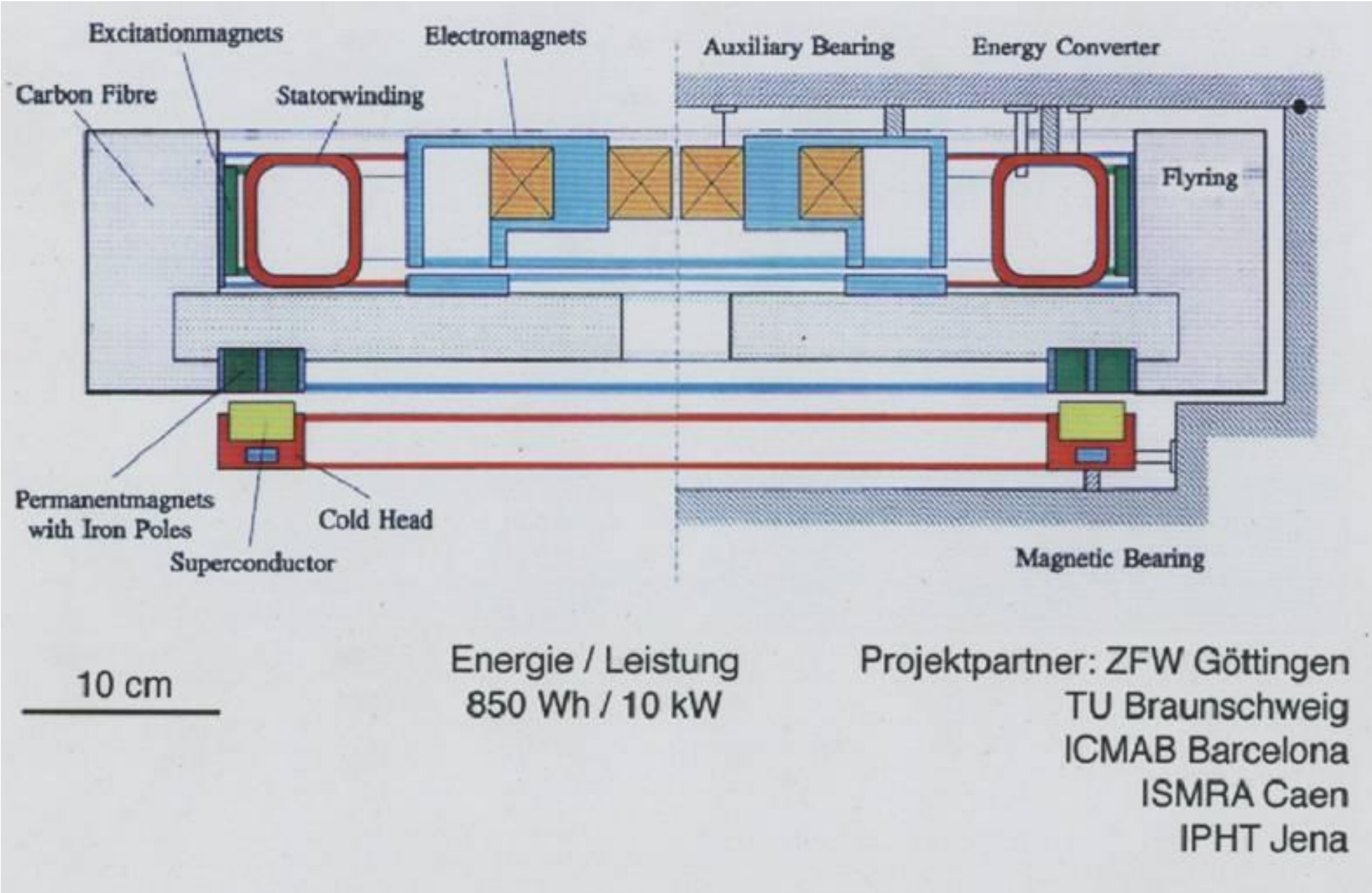


Conventional Magnetic bearing

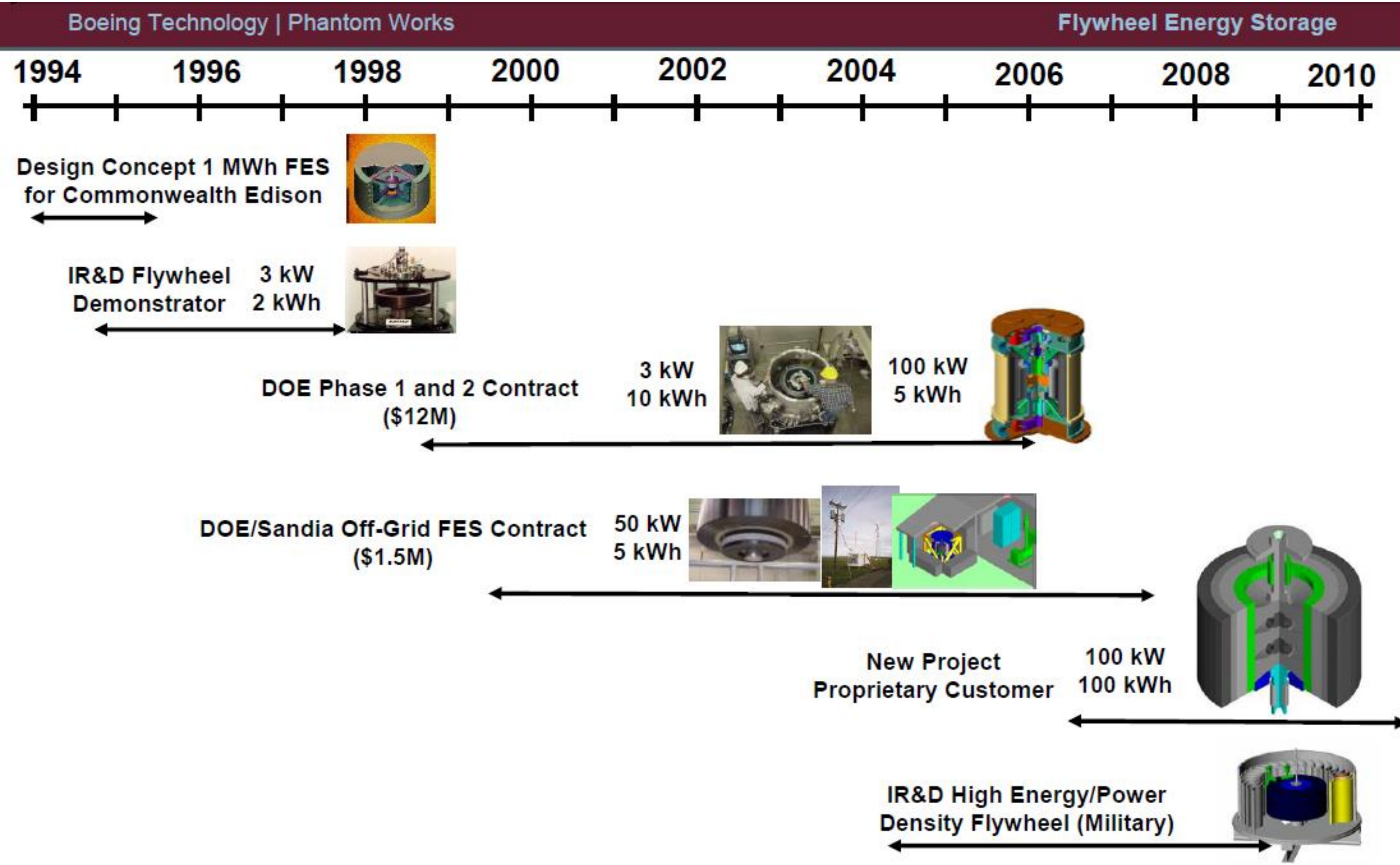
Low power cryocooler

Superconducting material includes its own feedback, including sensing

HTS F E S Early Projects 90's

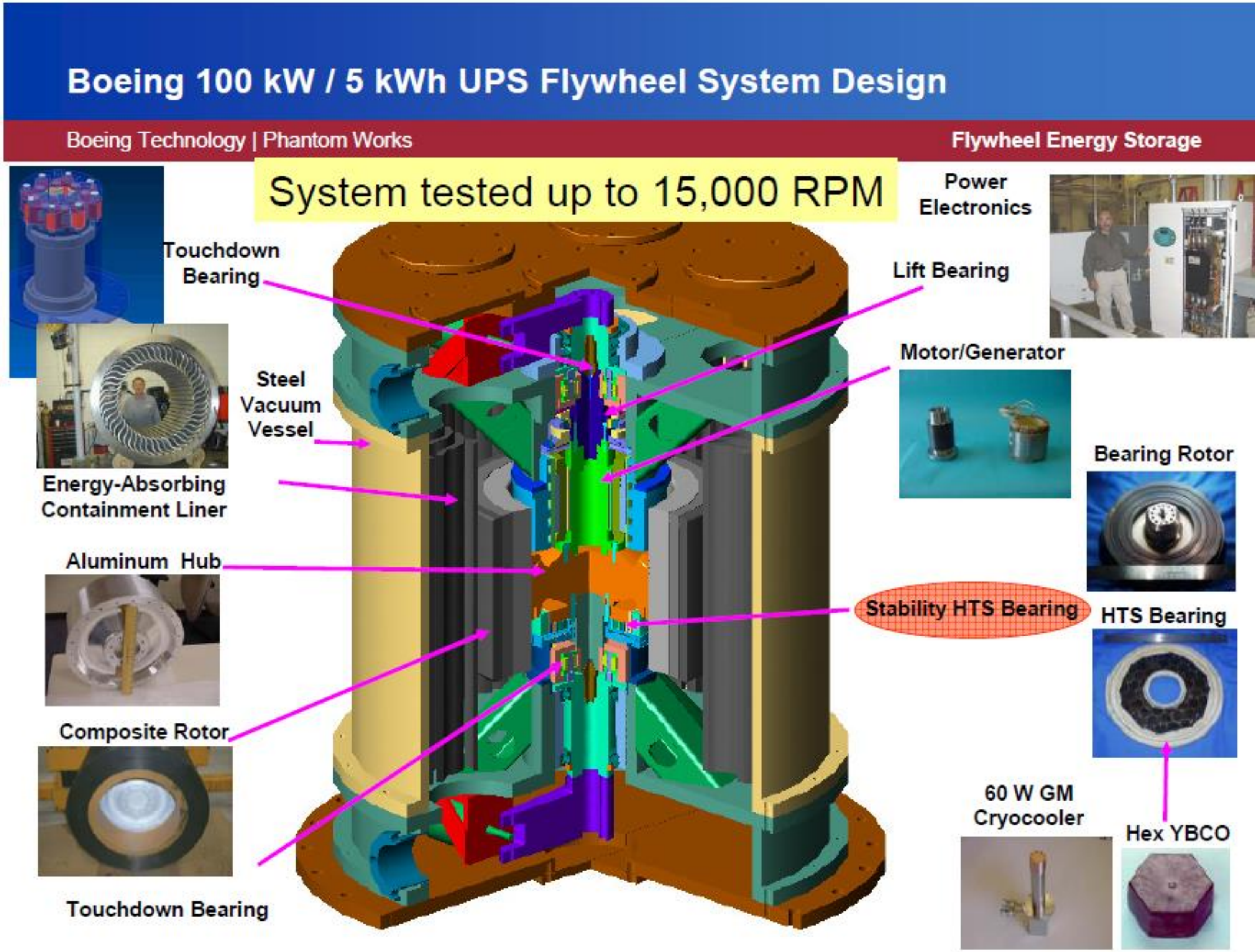


HTS F E S Phantom Project

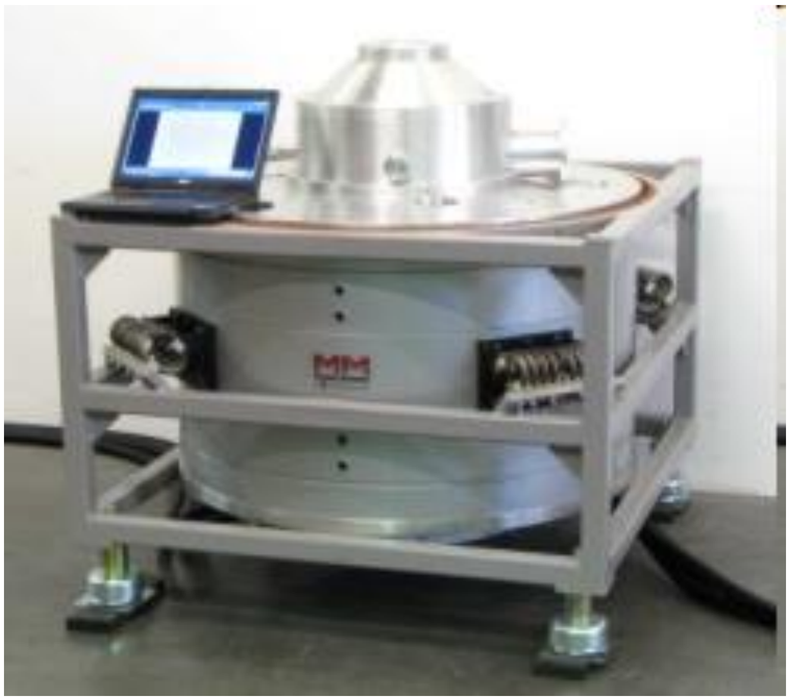


Strasik et al. Boeing Corp.

HTS F E S Phantom Project



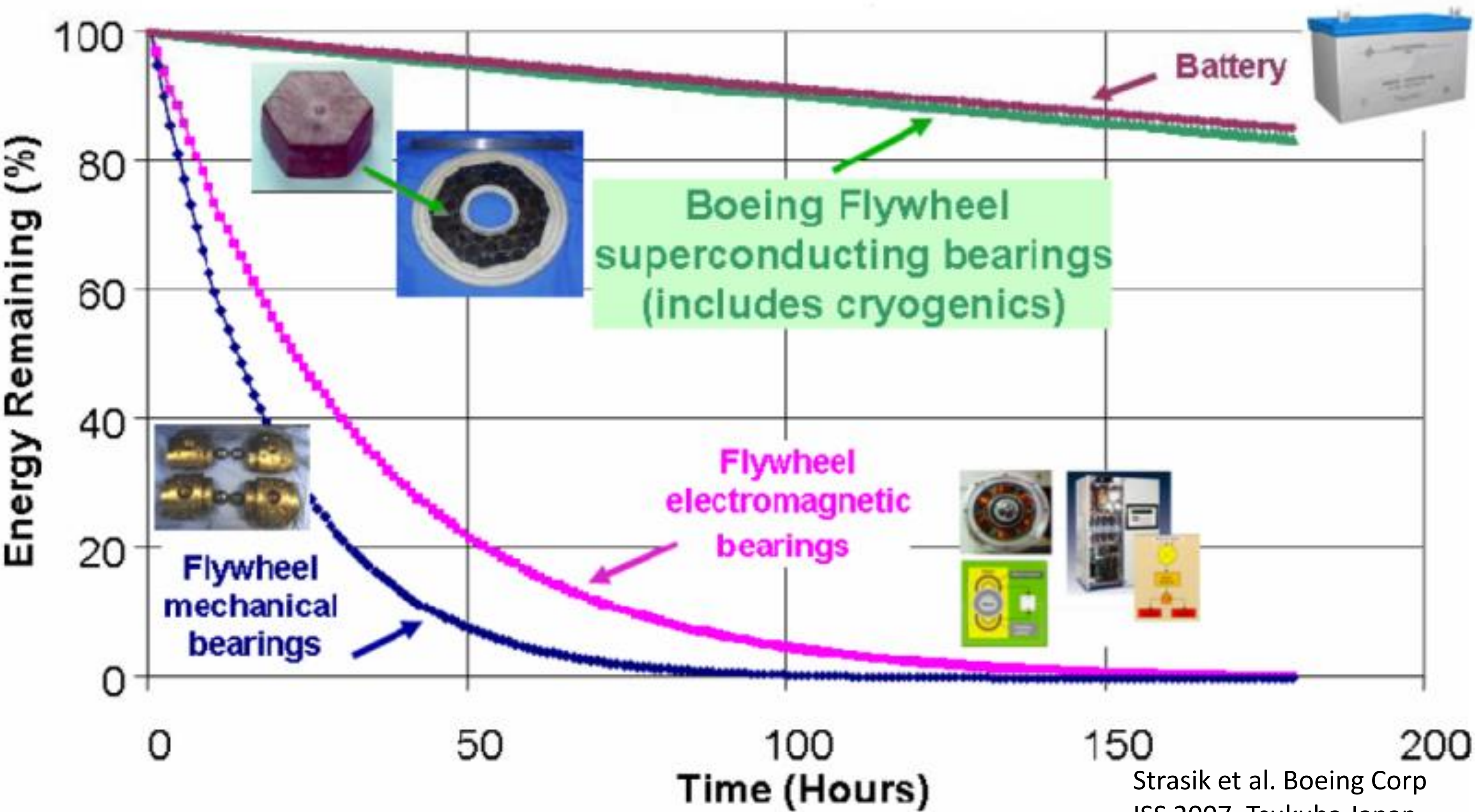
HTS F E S systems



Adelwitz Flywheel Energy Storage

Storage capacity: 5-6 kWh / 250 kW
HTS magnetic bearings, low loss
high rim speed (800 - 1000 m/s)
annular CF rotor body
low loss high power generator / motor
time to full power : 2 ms

HTS F E S Phantom Project



Strasik et al. Boeing Corp
ISS 2007, Tsukuba Japan.

Conventional versus HTS systems

Dynastore proposal IMAB, Braunsweig

	Coventional Flywheeel „Powerbridge“	Dynastore
Usable Energy	4 kWh	11kWh
Rated Power	1200 kW	2000 kW
Efficiency Stand By Losses	0,93 10 kW	0,94 1 kW
Mass	7000 kg	1200 kg
Dimensions	D = 1500 mm H = 2000 mm	D = 1500 mm H = 600 mm

Efficiency depends on the storage time

W.R Canders IMAB

Hybrid systems?

Short time

Turbine
synchro time

FES
SMES

Long time massive Energy Storage
Minutes-days

Liquid Air Energy Storage
(Air Products)

10MWh—1,000MWh (modular)
4h—12h
Up to 85%
$1,500—$2,000/kW

FLUX Batteries?
Electrochemical devices?

Electrochemical devices protection against peak currents: equalization.
Integrated in the converter (no additional power electronics).

Conclusions

Superconductivity plays a clear role in robust, fast, dense and efficient
In short term Energy Storage Systems (from ms up to some tens of minutes or hours)

Superconductivity can be easily combined with other efficient systems of long term Energy Storage to achieve a full time-scale operation.

Superconductivity Devices allow modularity and can be distributed being part of microgrids.

Superconductivity Devices could be integrated with Electrochemical Storage Systems in the converter for high peak power improvement

Superconductivity make possible the development of high reliability / maintenance-free mechanical systems as Super-Condensers.

Robust, Reliable, Energy Dense & Efficient