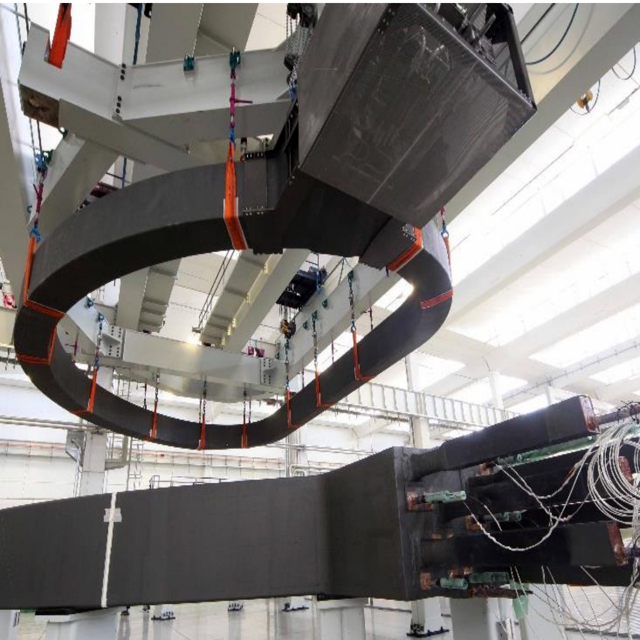
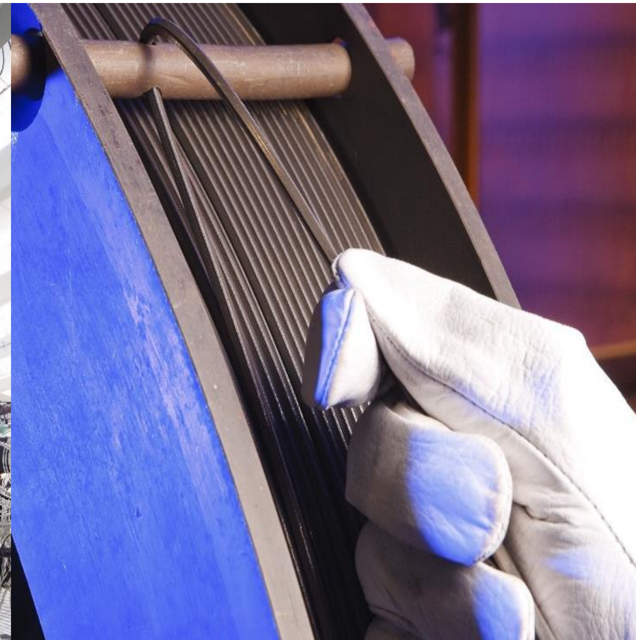




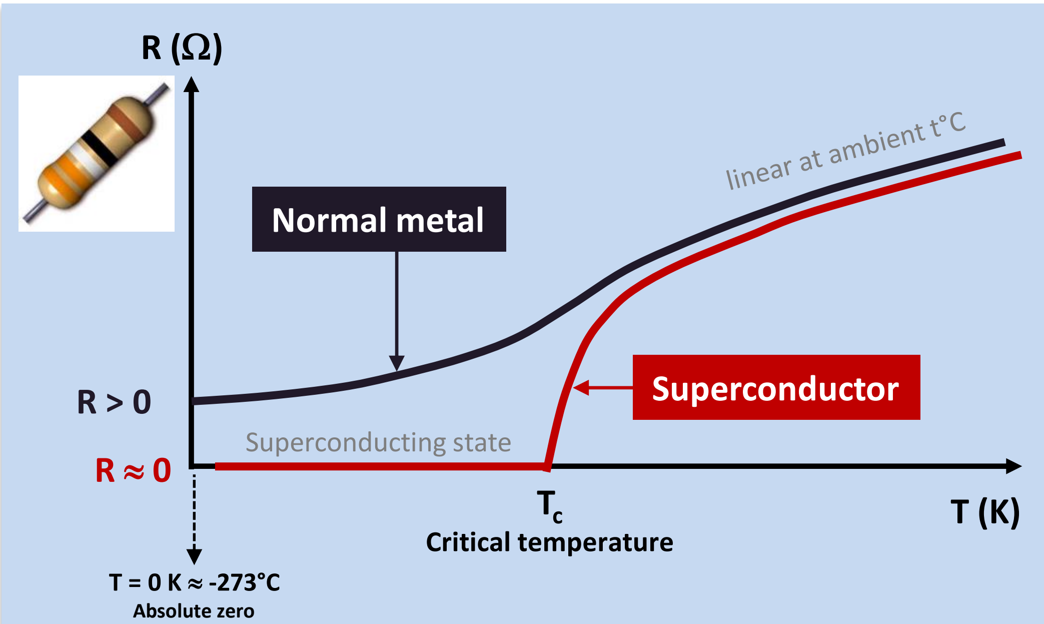
ASG Superconductors

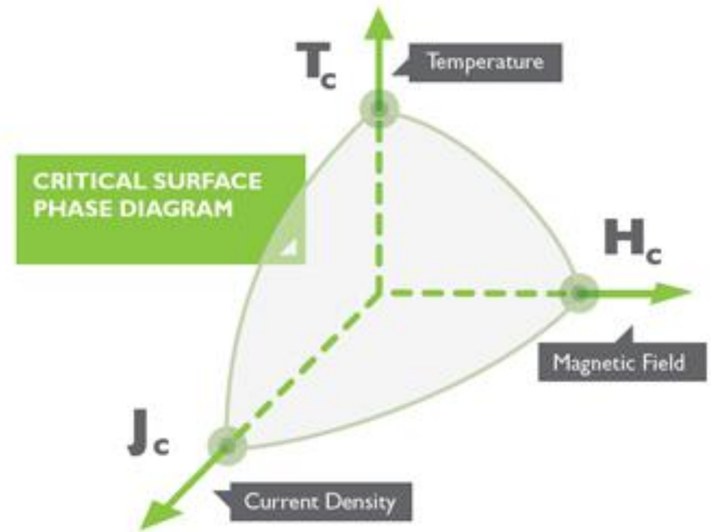
Company Profile

Columbus MgB2 Unit

www.asgsuperconductors.com

A superconductor is a material that shows
zero resistance below a critical temperature (T_c)





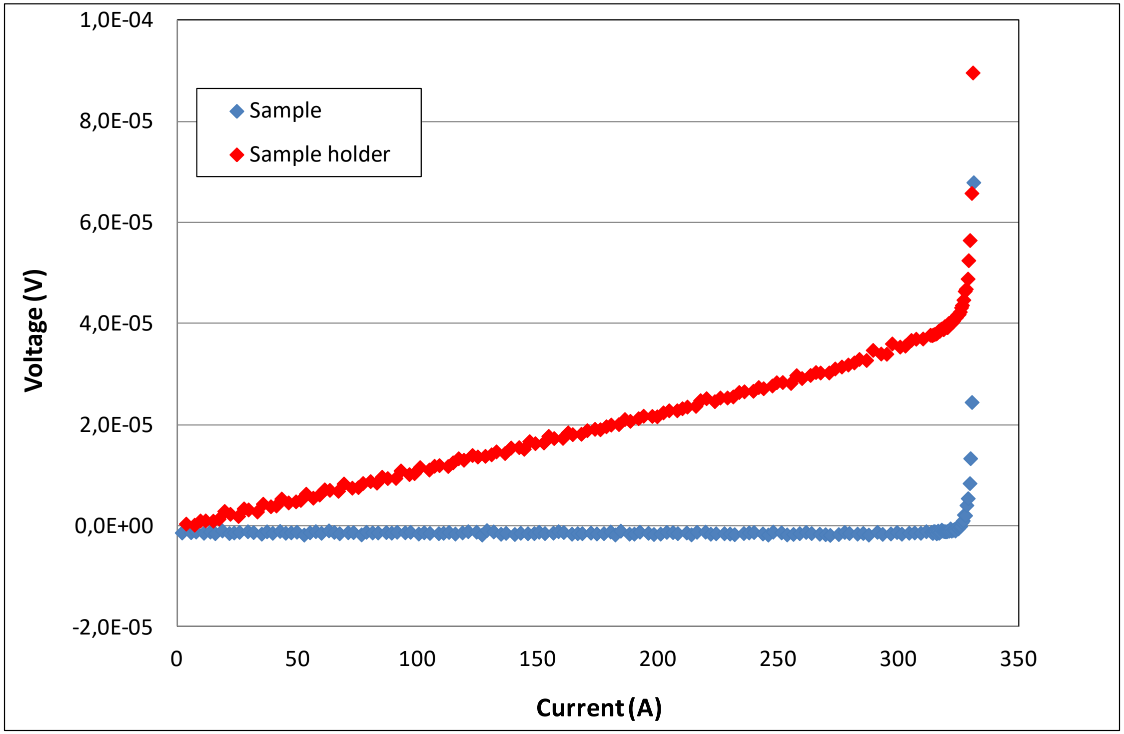
Superconductors are defined by 3 main parameters:
J_c: critical current density
T_c: critical temperature
H_c: critical magnetic field

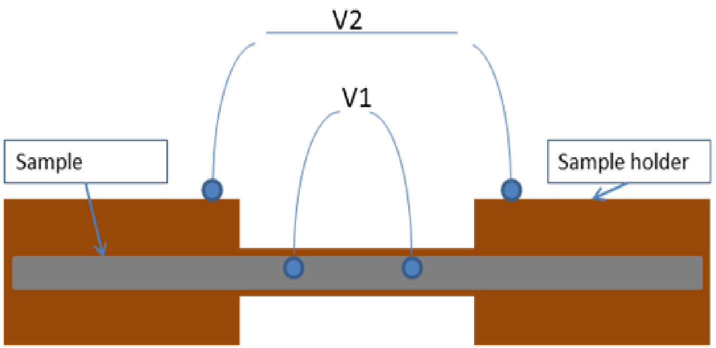
zero resistance ⟷ **zero power dissipation**

•Transport method

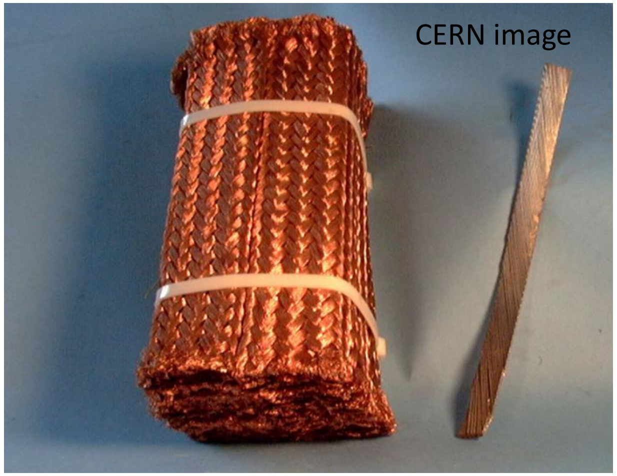
current (I) passes through the sample and the voltage (V) is measured along it

•The criteria to determine the Ic is 1 μV cm

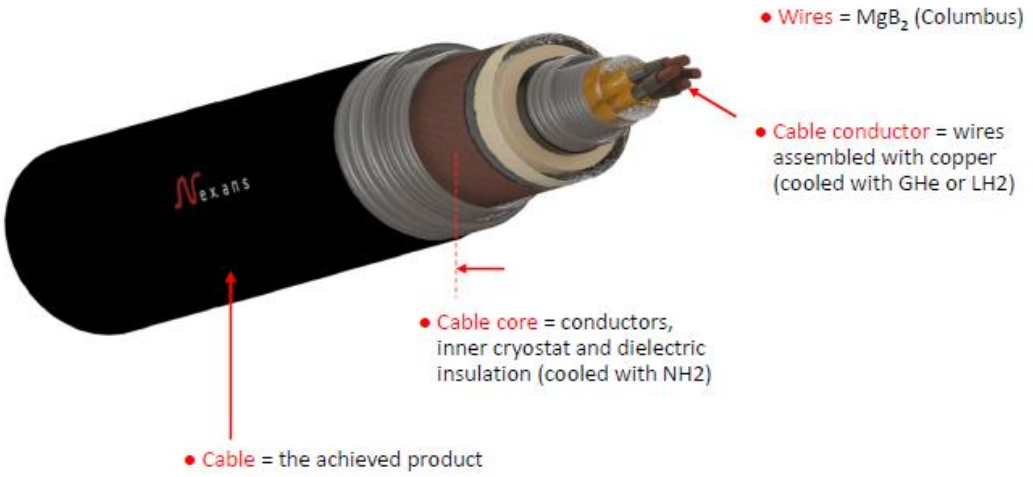


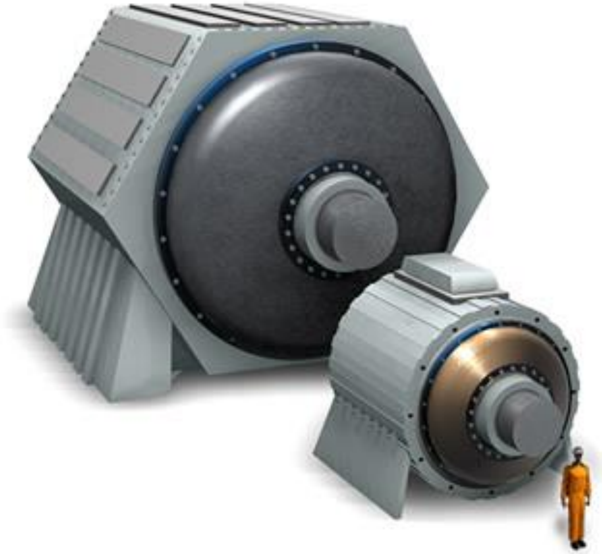


Copper wires Vs Superconducting wires



11 x 8 cm^2 copper @T= 300K NbTi@T=1.8K
12800 Amps





SC electric machine (generator, motor)

- 2-3x size reduction
- weight and volume reduction
- higher efficency
- cost saving

Power Cables
Energy Storage
Fault Current Limiter

MRI

MRI machine

Paramed image

Siemens image

- The progress in MRIs is strongly linked to the creation of new devices with always-stronger fields

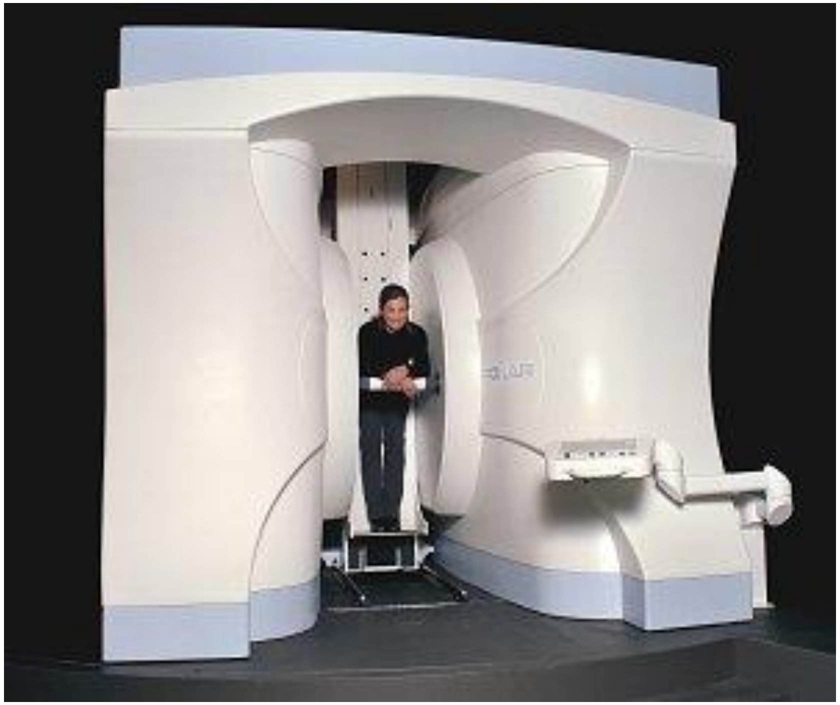
- Stronger the **magnetic field**
- Stronger the signal
- Better the images

- The main magnetic field is created by a large superconducting electromagnet in which a current flows

- The weak resistance of superconductors allows very strong currents to flow with **no heating in the material**, and hence enables to get very high field values of several tesla.

Copper wires Vs Superconducting wires

MRI with copper wire (FONAR)



- 200 tons
- 200 KWatt power needed

Risonanza magnetica con avvolgimento in superconduttore MgB_2 (PARAMED)

- 25 Tonnellate
- 16 KWatt di potenza impegnata
- Cryogenics required:
  - liquid Helium or cryocooler

Critical temperatures plot

T = 0°C ≈ 273 K
(water becomes ice)

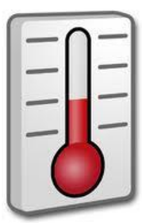
Ambient temperature

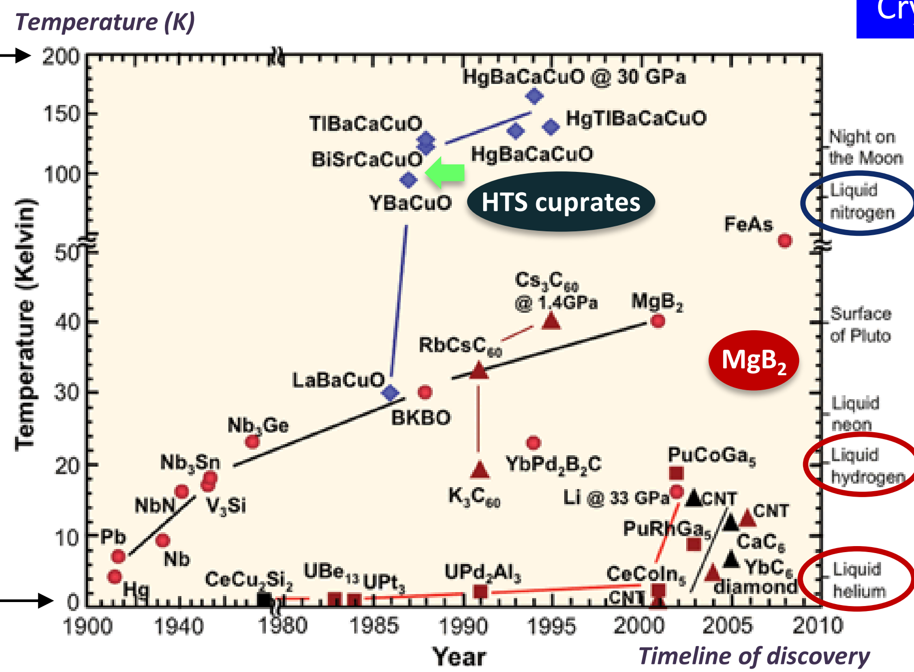
Superconducting materials

Cryogenic fluids

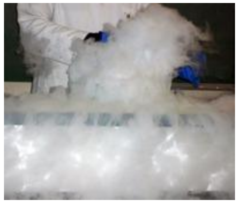
T = 200 K ≈ -73°C

Industrial cooling





Liquid nitrogen

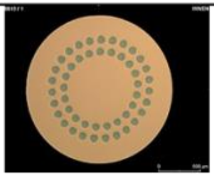
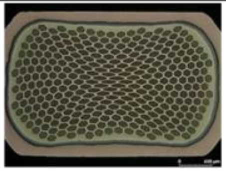
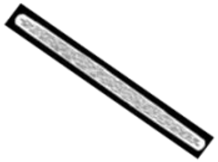
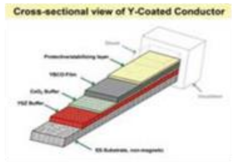


Liquid hydrogen

Liquid helium

Extreme cold

T = 0 K ≈ -273°C
Absolute Zero
(lowest temperature that can be reached in the universe)

	LTS			HTS	
	NbTi	Nb_3Sn	MgB_2	BSCCO	YBCO
Wire type					
T_c (K)	9 K	18 K	39 K	108 K	90 K
B_{c2} (T)	10 T	28 T	Up to 70 T	>100 T	>100 T
Operation in dry magnets above 10 K	NO	NO	**YES**	YES	YES
Ductile compound	YES	NO	NO	NO	NO
Flexible wires	**YES**	NO	**YES**	YES	YES
Superconducting splices	**YES**	YES	**YES**	NO	NO
Low cost (< 5 $/m)	**YES**	NO	**YES**	NO	NO (not before 5 years)
Long lengths (>2 Km)	**YES**	YES	**YES**	NO	NO

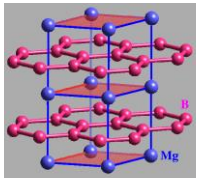
Thanks to its features MgB_2 represent a new option in the medical-MR field

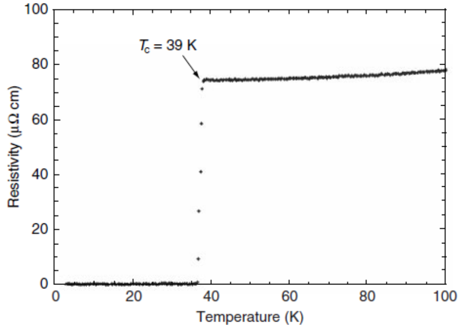
- low cost in comparison to HTS
- higher temperature margin in comparison to LTS
- liquid helium crisis: demand will exceed the supply
- MRI industry is working towards conduction cooled system instead of LHe baths

Columbus Superconductors

MgB_2 properties

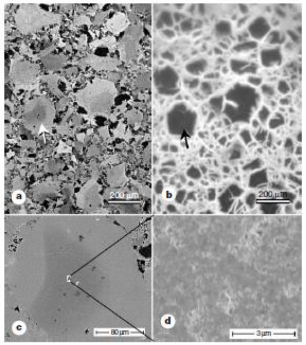
Relatively high Tc, simple structure and common materials





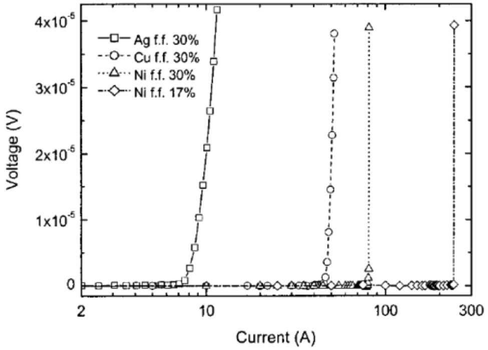
Nagamatsu et al. 2001
Superconductivity at 39K in magnesium diboride
Nature 410 63-4

No evidence of "weak link", no need of high degree of texturing



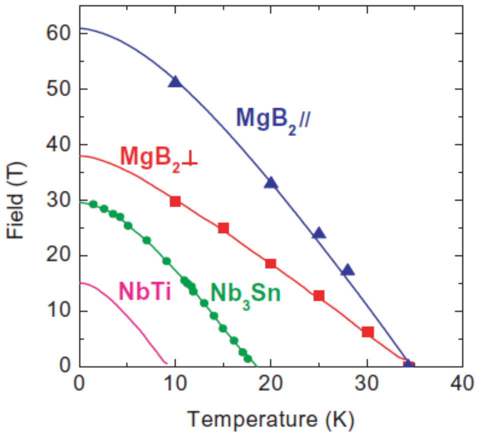
D.C Larbalestrier et al. 2001
Strongly linked current flow in polycrystaline form of the superconductor MgB_2
Nature 410

PIT process for the fabrication of wire



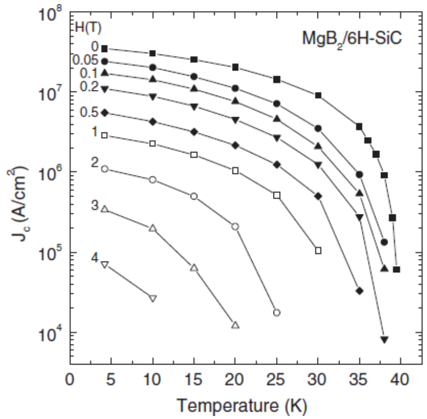
G.Grasso et .al. 2001
Large transport current in unsintered MgB_2 SC tapes
APL Volume 72, number 9

High critical field



Iwasa Y et al. 2006
A round table discussion on MgB_2:
towards a wide market or a niche production?
IEEE Trans. Appl. Supercond 16 1457-64

Large critical current density



Zeng et al. 2003
Superconducting MgB_2 thin film
on silicon carbide substrate by HPCVD
APL 82 2097-9

Low density

Compound	Mass density
Copper	8,96 g/cm^3
NbTi	6 g/cm^3
Nb3Sn	5,4 g/cm^3
YBCO	6,35 g/cm^3
BSCCO-2223	6,5 g/cm^3
MgB_2	2,6 g/cm^3

MgB_2 wire manufacturing companies

Hyper Tech Research, Inc.

Columbus Superconductors

Ready for industrial production
2 different manufacturing process
ex-situ and in-situ technique

EPOCH WIRES
infinite superconductivity

Early stage company, 2013,
Based in Cambridge UK
granted by UK SMART
for R&D activities on MgB_2

Cutting Edge Superconductors Inc.

Interested in industriall production
of wires or wires+magnet

Located in Portorico
MgB_2 wires for Cryo-free MRI
MRI magnet, open 1.5T, 3T

Interested in the MgB_2 technology

SUPERCON INC

Western Superconducting Technologies Co., Ltd.

BRUKER

Bruker BEST

1000 m of MgB2 wire
already demonstrated
in collaboration with IFW Dresden

GE Global Research

HITACHI

SIEMENS

Patents on MgB2 wires
Several R&D activities
Published paper

2003

Columbus Superconductors srl

75% CNR+Researchers
25% ASG

2005

R&D target

First 1.6 km MgB_2 long wire in a single unit length

2006

Columbus Superconductors SpA

ASG became the main shareholder to sustain industrial investment and to start the business plan

Superconducting wire	Superconducting magnet	MRI
Columbus Superconductors	ASG Superconductors	PARAmed Medical Systems

Columbus Superconductors

World leader in the cutting-edge technology of a superconducting material MgB2 and its transformation into long, versatile and very reliable superconducting wires.

PARAmed MEDICAL SYSTEMS

Specialist in advanced MRI-enabled solutions. OPEN MRI systems is the only superconductive MRI with a "totally open" magnet design, that allows Multi-position imaging.

ASG Superconductors

World leader in terms of superconducting magnetic systems design, construction and testing capabilities for research, medical and power quality applications.

ASG SUPERCONDUCTORS

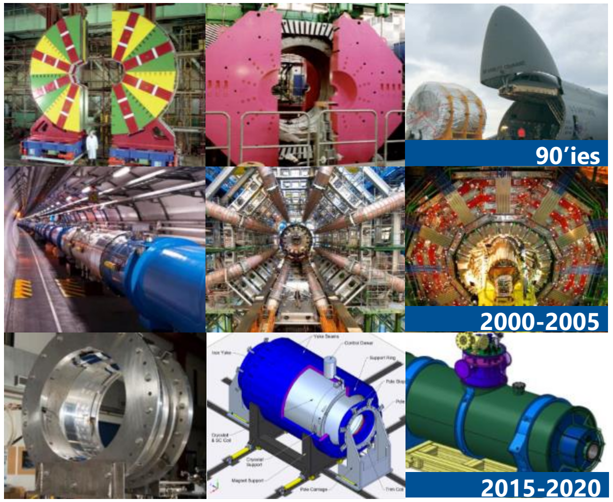
- Magnets
- Med-Tech
- MgB2

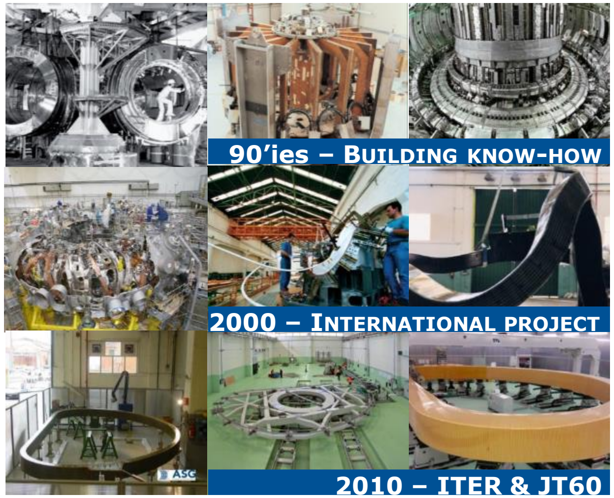
230 EMPLOYES (including subsidiaries), with an Engineering staff of 70

38,000 m² PRODUCTION PLANT OVER 4 PLANTS IN LIGURIA (ITALY)

Design and manufacturing of **SUPERCONDUCTING MAGNETS** and ancillary systems in the field of:

HIGH ENERGY PHYSICS	THERMONUCLEAR FUSION	INDUSTRIAL APPLICATIONS





Columbus MgB2 wire unit

This unit is a **world leader in cutting-edge magnesium diboride (MgB2) technology** and the transformation of this superconducting material into long, versatile and **highly reliable superconducting wire.**

MgB2 is one of the most recent solutions adopted by the superconductor industry, the **high superconducting temperature** (Tc= 40 K) means that MgB2-based systems can be cooled by **modern cryocooling devices, without the costly, problematic and hazardous use of liquid helium.**

MgB2 wire technology is already tested and used in energy, power, medical and high energy physics.

MGB2 WIRES FOR CABLES

MGB2 WIRES FOR MAGNETS

MGB2 WIRES FOR MRI

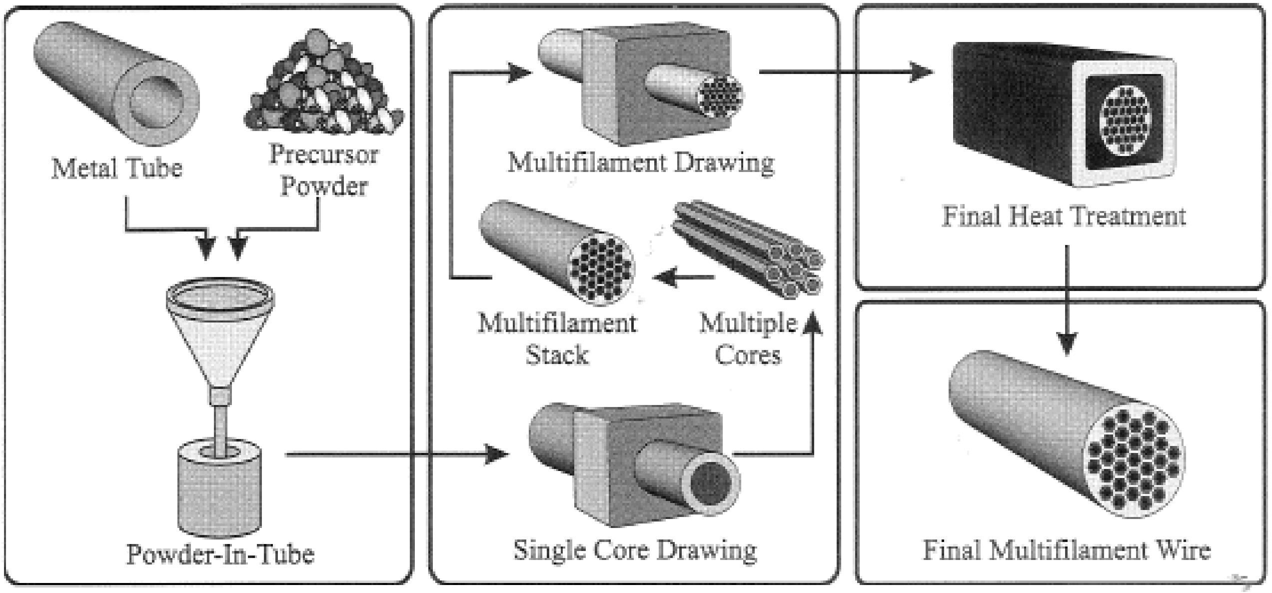
MGB2 CABLES

ASG SUPERCONDUCTORS
columbus mgb2 unit

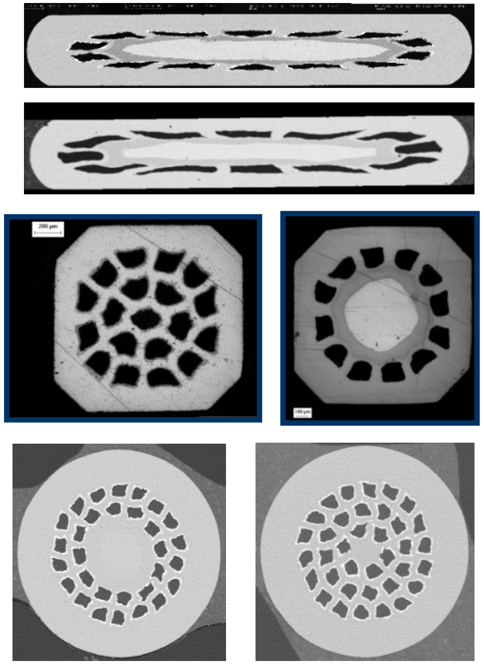
- The actual plant is fully operational for **MgB_2 wire production** with about 35 employees
- **MgB_2 chemical synthesis** also fully implemented

- Wire unit length today up to **2- 4 Km in a single piece**
- It will be possible up to **12-13 Km** with the full scale up of the process

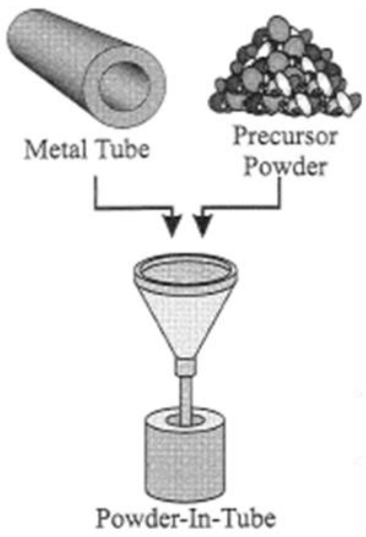
- Columbus **MgB_2 wires production for MRI and cables application** has exceeded **600 Km** of fully tested and qualified wires



Conductors configuration:
different shape, aspect ratio, number of filaments, materials

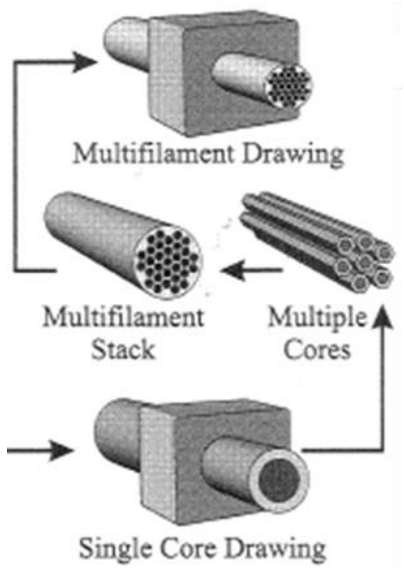


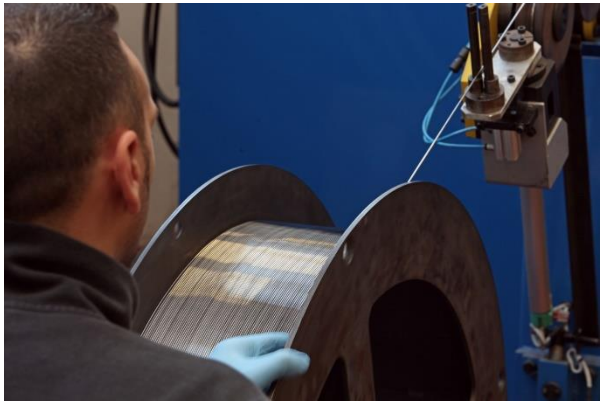
Home made MgB_2 powders
Precursor quality, doping synthesis temperature, granulometry

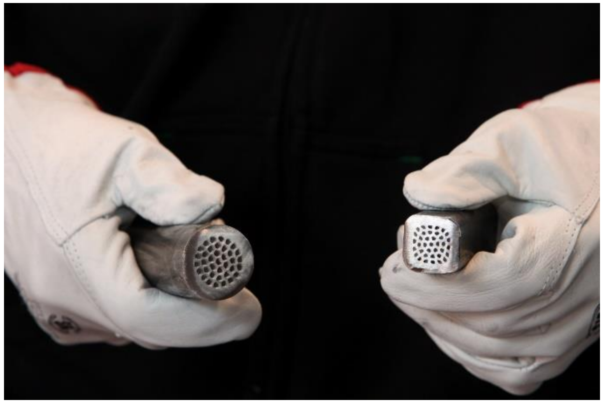


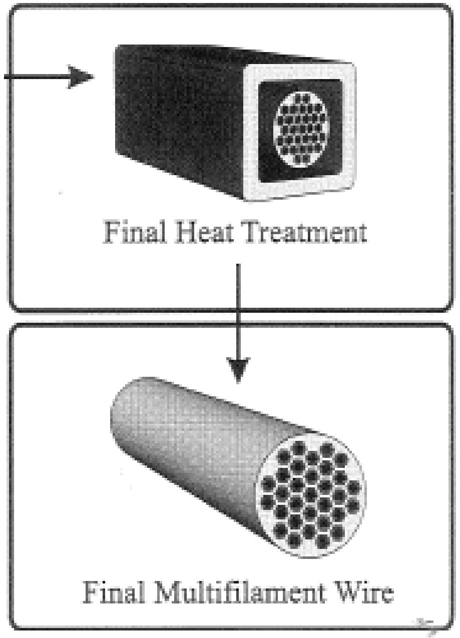
Powder optimization

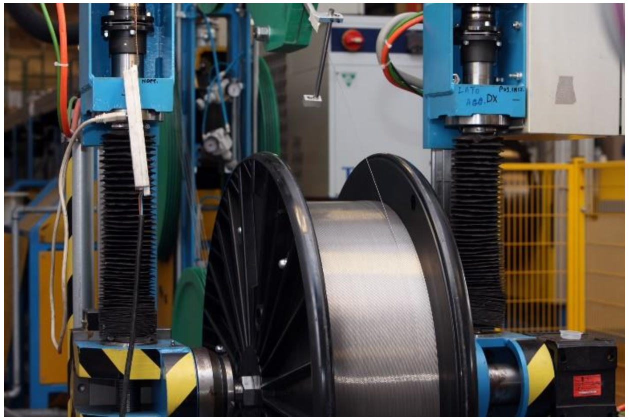
- Purity and granulometry control
- Grain connectivity
- MgO at grain boundaries
- Pinning and/or doping control

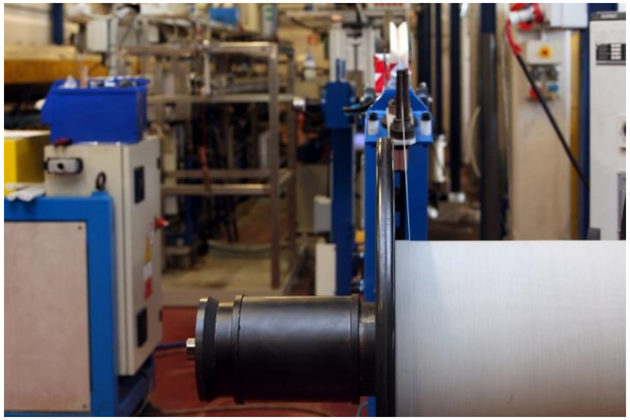

Multifilament Drawing
Multifilament Stack
Multiple Cores
Single Core Drawing

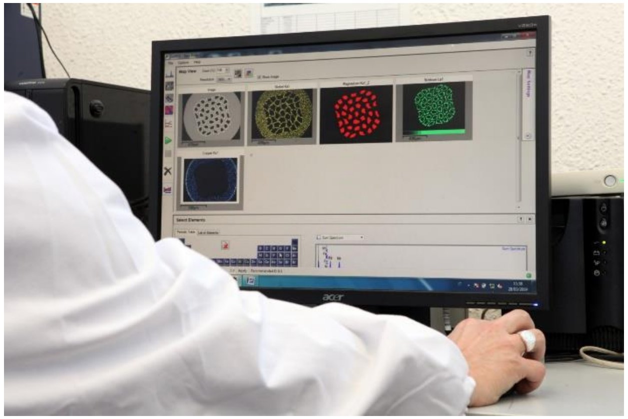





Final Heat Treatment
Final Multifilament Wire



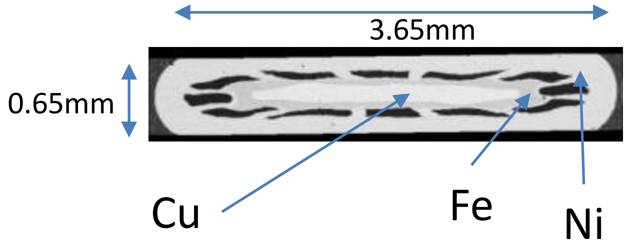




Tape solution for MRI

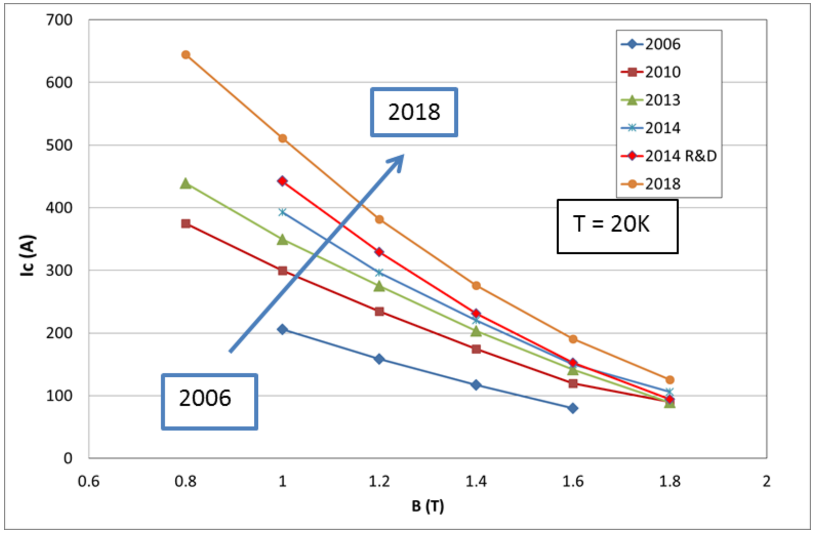
Original MR-Open conductor

- Wire product we used to validate our MgB_2 technology
- It showed us that MgB_2 can be produced with high yield and low cost – still in production today
- Two-fold improvement in performance – 50% less wire needed

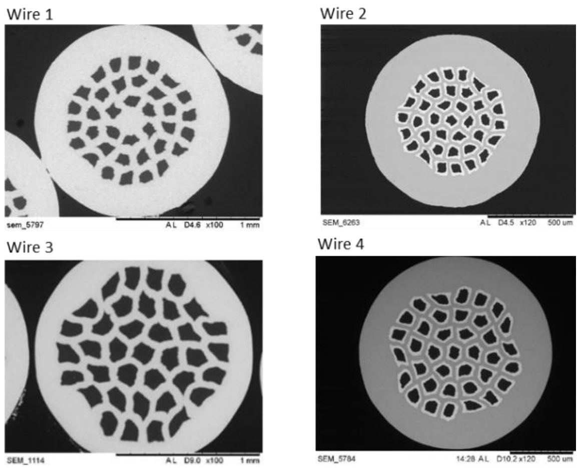


Updated wire layout:

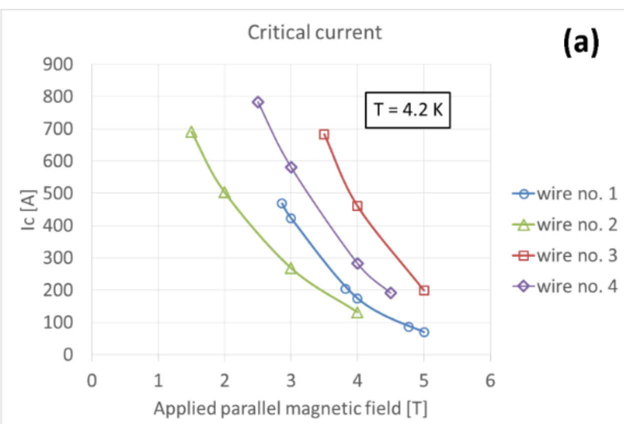
- 12 filaments
- Improved fabrication process
- Unit piece length 4.0 Km
- Synthesis in controlled atmosphere

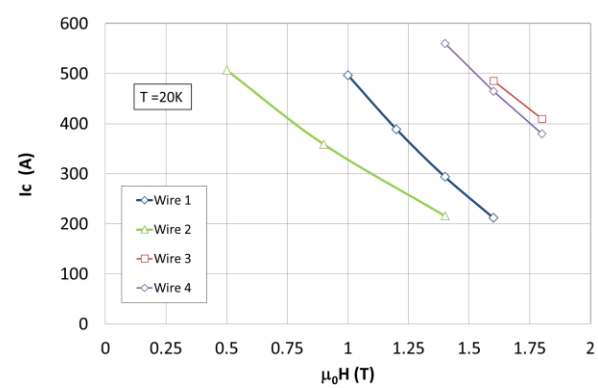


2018



PROPERTIES	Wire 1	Wire 2	Wire 3	Wire 4
Diameter (mm)	1.3	1	1.5	1.5
Materials	Monel Nickel	Monel Nickel Nb	Monel Nickel	Monel Nickel Nb
MgB2 fraction	17%	12%	30%	12%
Critical current at 20K, 1T	500A	300A	>650A	>650A
Critical current at 4.2K, 3T	280	400	>700	600
Critcal bending radius	125	100	200	150





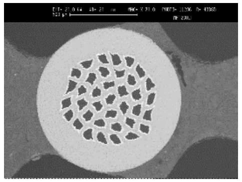
ROUND WIRES

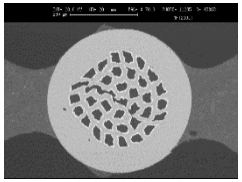
IOP Publishing
Superconductor Science and Technology
Supercond. Sci. Technol. 27 (2014) 044024 (7pp)
doi:10.1088/0953-2048/27/4/044024

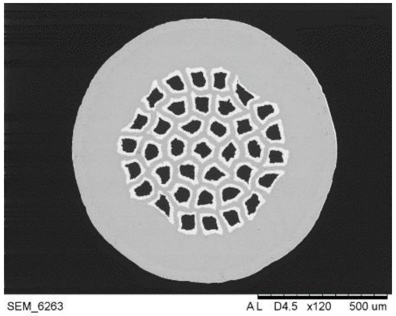
Development of superconducting links for the Large Hadron Collider machine

Amalia Ballarino

CERN, European Organization for Nuclear Research, 1211 Geneva 23, Switzerland







Supercond. Sci. Technol. 27 (2014) 044024 A Ballarino

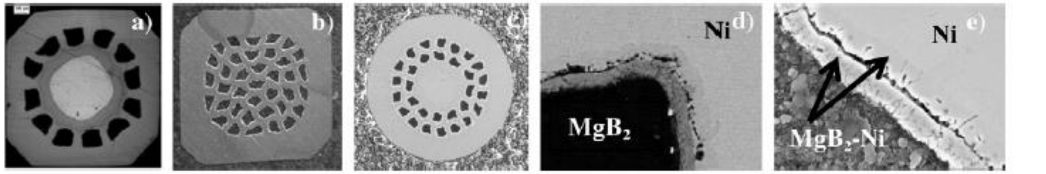


Figure 3. Different generations of MgB_2 Columbus round wires. From left: (a) S1 octagonal wire with nickel matrix and central copper stabilizer surrounded by iron barrier; (b) S2 quasi-square wire with Monel matrix and nickel barrier around the filaments; (c) S3 round wire with Monel matrix and niobium barrier around the filaments; (d) and (e) SEM cross section imaging of wire S2 [8]: porosity and detachment in between the two MgB_2–Ni reaction layers.

Diameter of MgB_2 wire, Φ	$0.8 \text{ mm} \leq \Phi < 1 \text{ mm}$
Diameter of superconducting filaments	≤ 60 μm
Filaments twist pitch	≤ 100 mm
Filaments twist direction	Right-handed screw
Critical current at 25 K and 0.9 T	≥ 186 A
Critical current at 25 K and 0.5 T	≥ 320 A
Critical current at 20 K and 0.5 T	≥ 480 A
Bending radius (after final heat treatment)*	≤ 100 mm
Tensile strain at room temperature*	≥ 0.28%
Copper fraction of the wire total cross section	≥ 12%
RRR of copper stabilizer	> 100
*n-value*** @ 25 K and 0.9 T	> 20

More than 500 km already deliverd and qualified

Critical issues

Various issues:

Powder optimization

- Purity and granulometry control
- Grain connectivity
- MgO at grain boundaries
- Pinning and/or doping control

Sheath materials

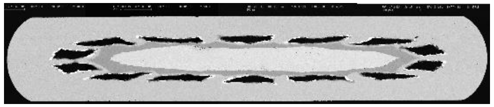
- Mechanical properties of the raw metals
- MgB_2 / sheath reaction

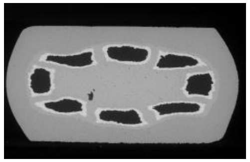
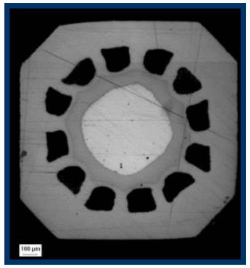
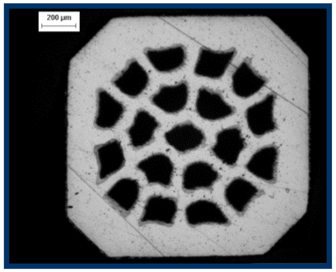
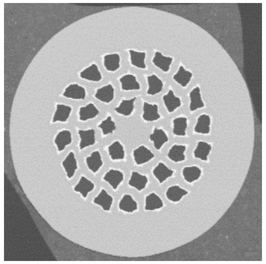
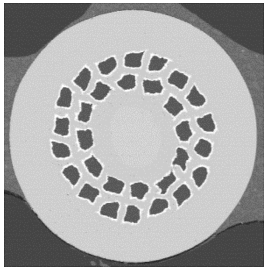
Optimization of intermediate (500-800°C) and final thermal treatment (900°C)

Application voted design

Layout of the conductor: shape, dimensions, number of filament

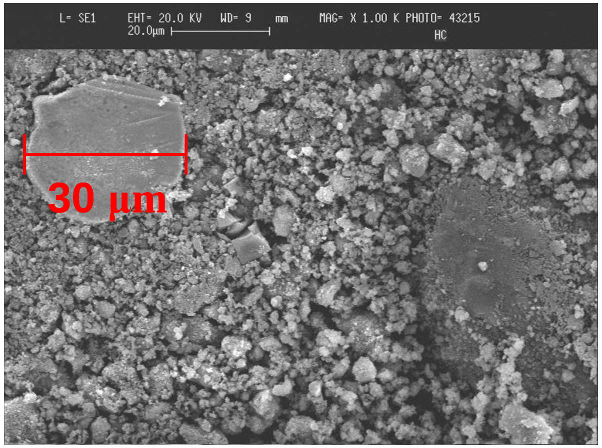
Magnetic, electrical, thermal and mechanical properties



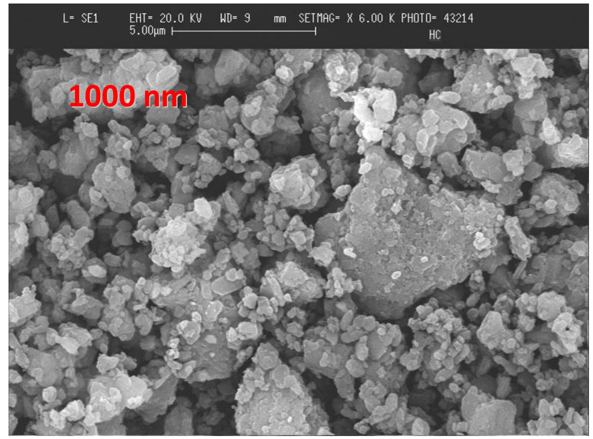






Powder granulometry control

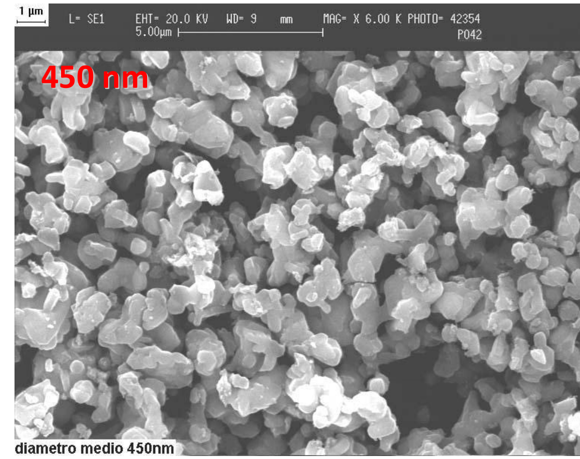
Control of **powder production** process is crucial to achieve optimal particle size



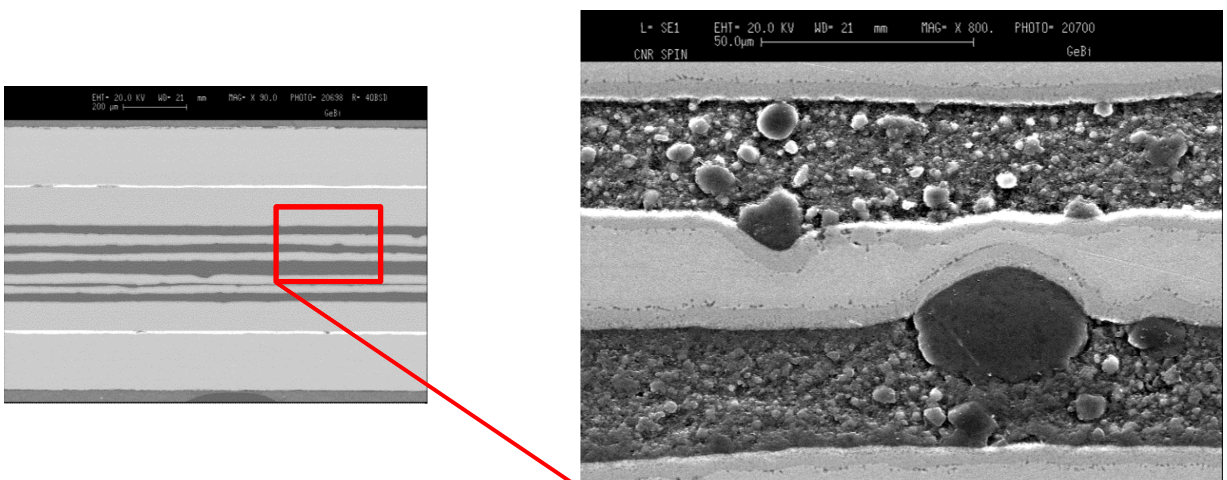
Commercial MgB_2



MgB_2 from commercial Boron



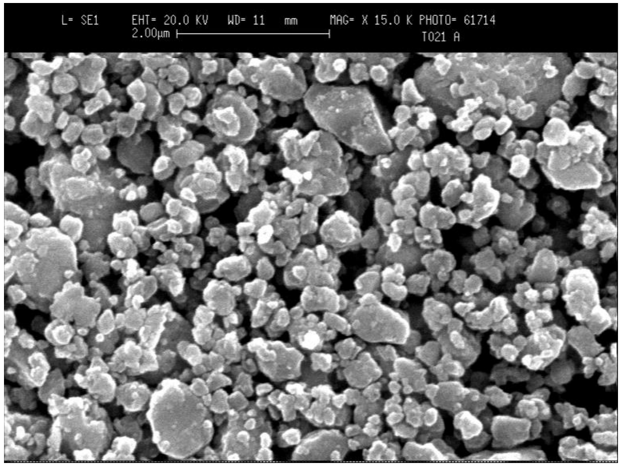
MgB_2 from special Boron



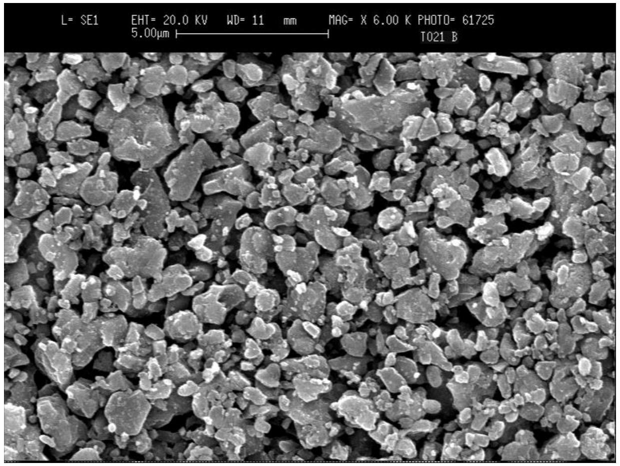
With controlled powder it is possible to obtain better **homogeneity of the filament** cross section and also **thinner filaments**

Powder granulometry control

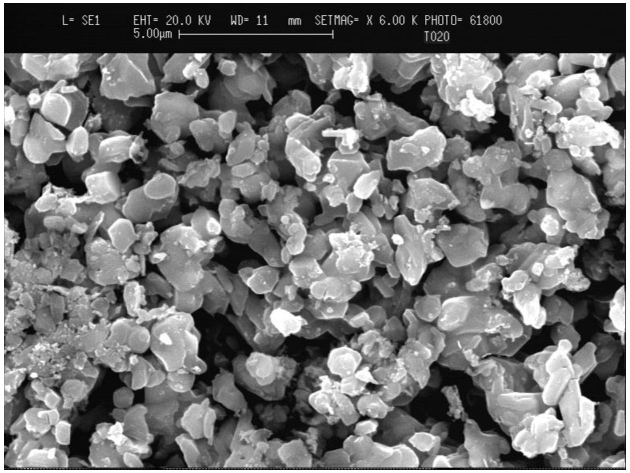
2µm Milled 144h



5µm Milled 77h



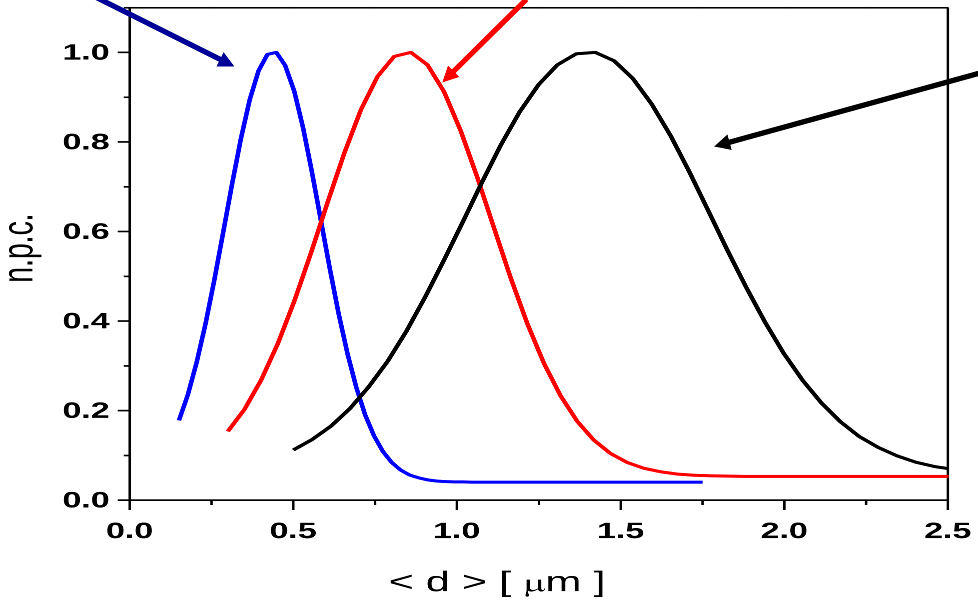
5µm Not milled



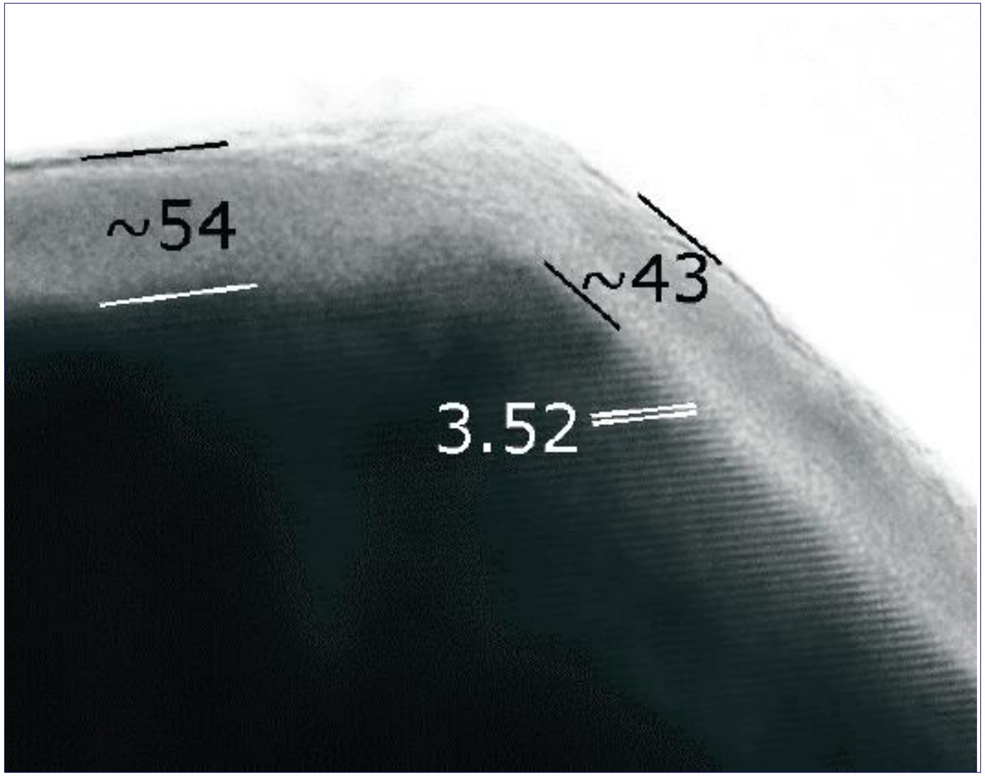
< d > = 440 nm

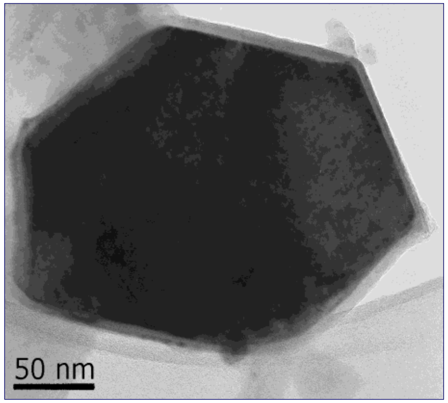
< d > = 850 nm

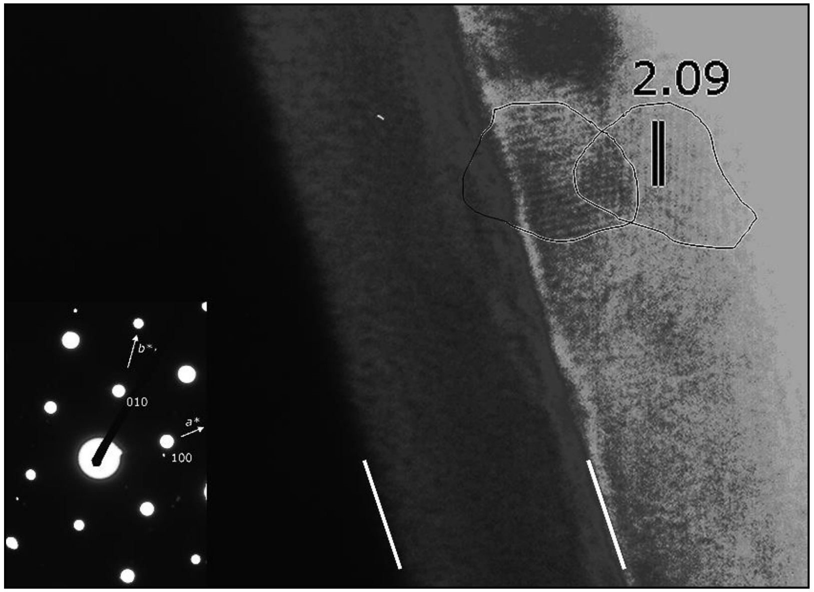
< d > = 1.4 µm



MgO at grain boundaries: TEM analysis



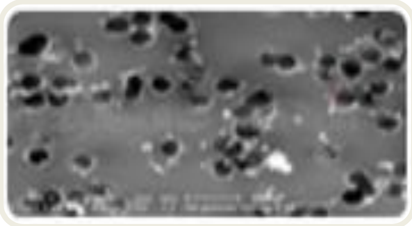




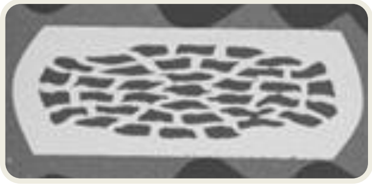
MgB_2 grains are covered with **amorphous MgO** layer of ~50 Å, comparable with MgB_2 coherence length: working in **oxygen cleaner conditions** is mandatory!

Essential for wire Jc enhancement

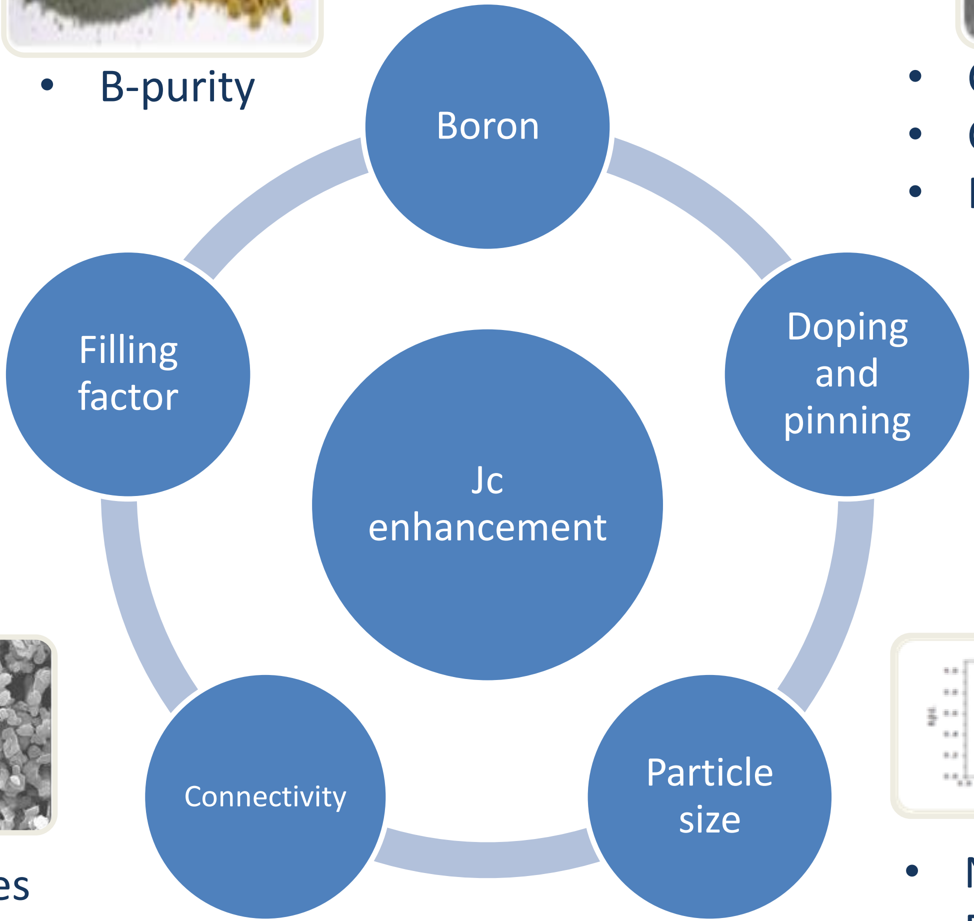
- B-purity

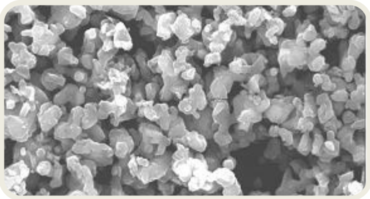


- C-doping
- C-encapsulated B
- Pinning

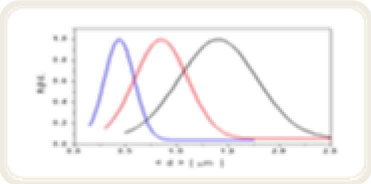


- FF from 16% to 33%



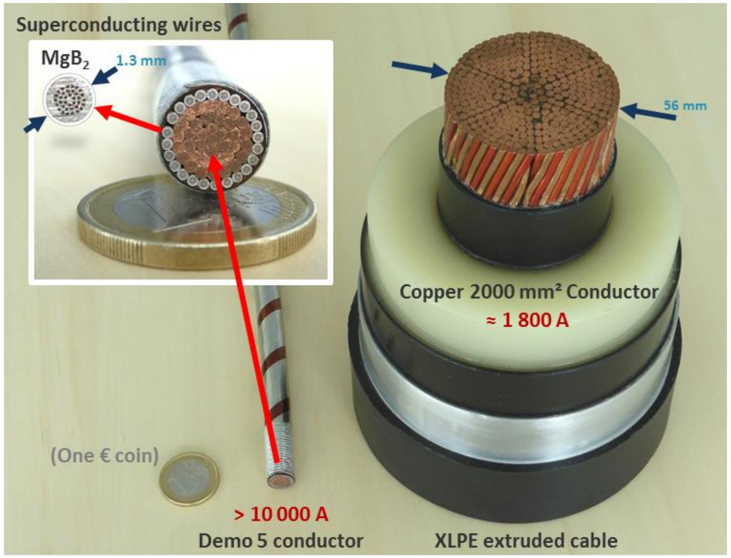


- Grain boundaries
- Wire design
- Deformation process



- Number of filaments
- Filaments size
- MgB_2 density
- In field behaviour

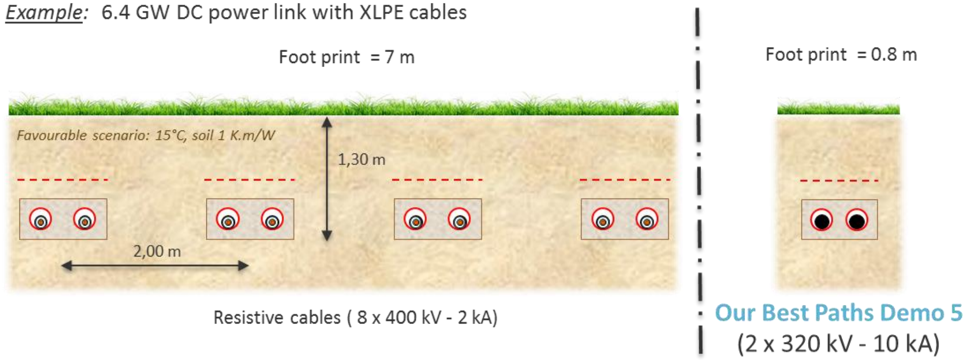
Reduction of raw materials



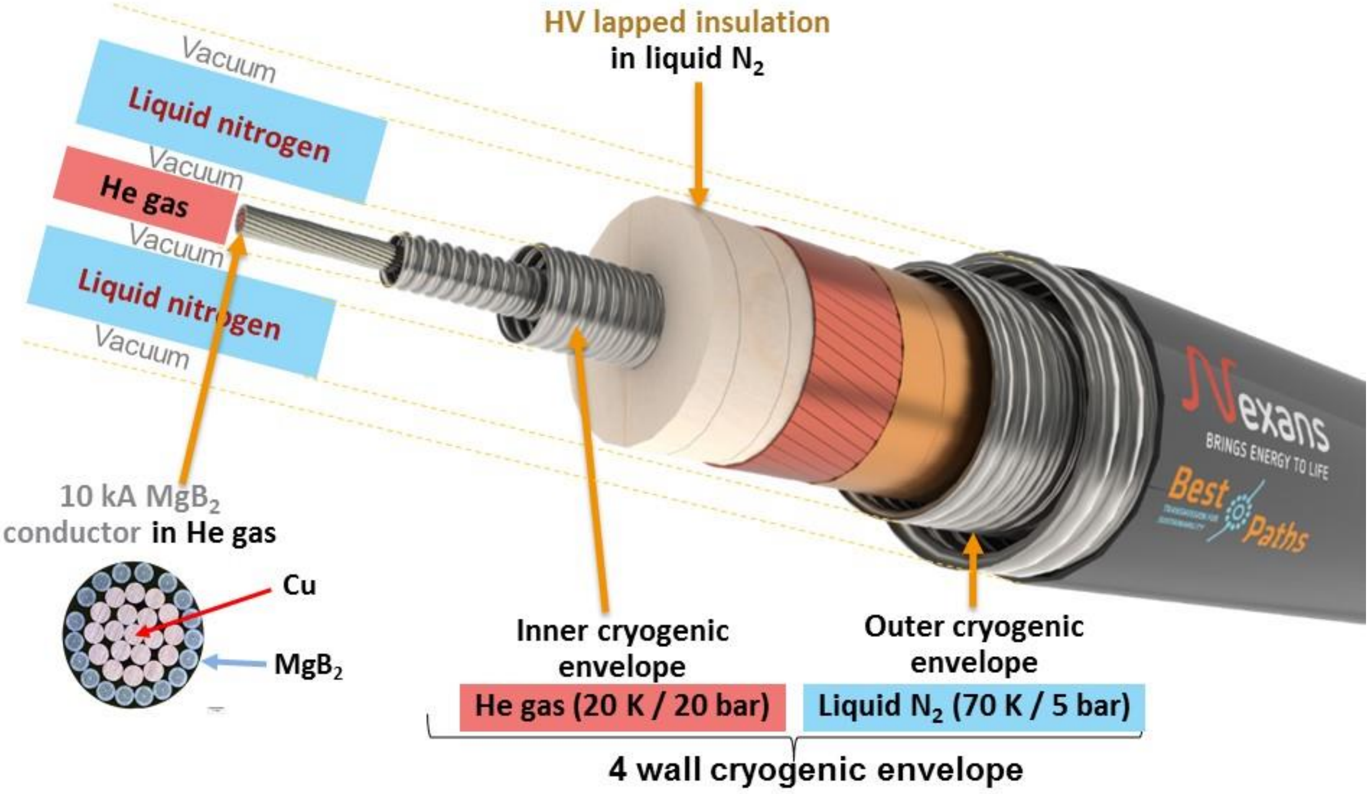
Footprint
Reduced space for installation

Significant reduction of right-of-way corridors and of excavation work

No thermal dependence to the environment

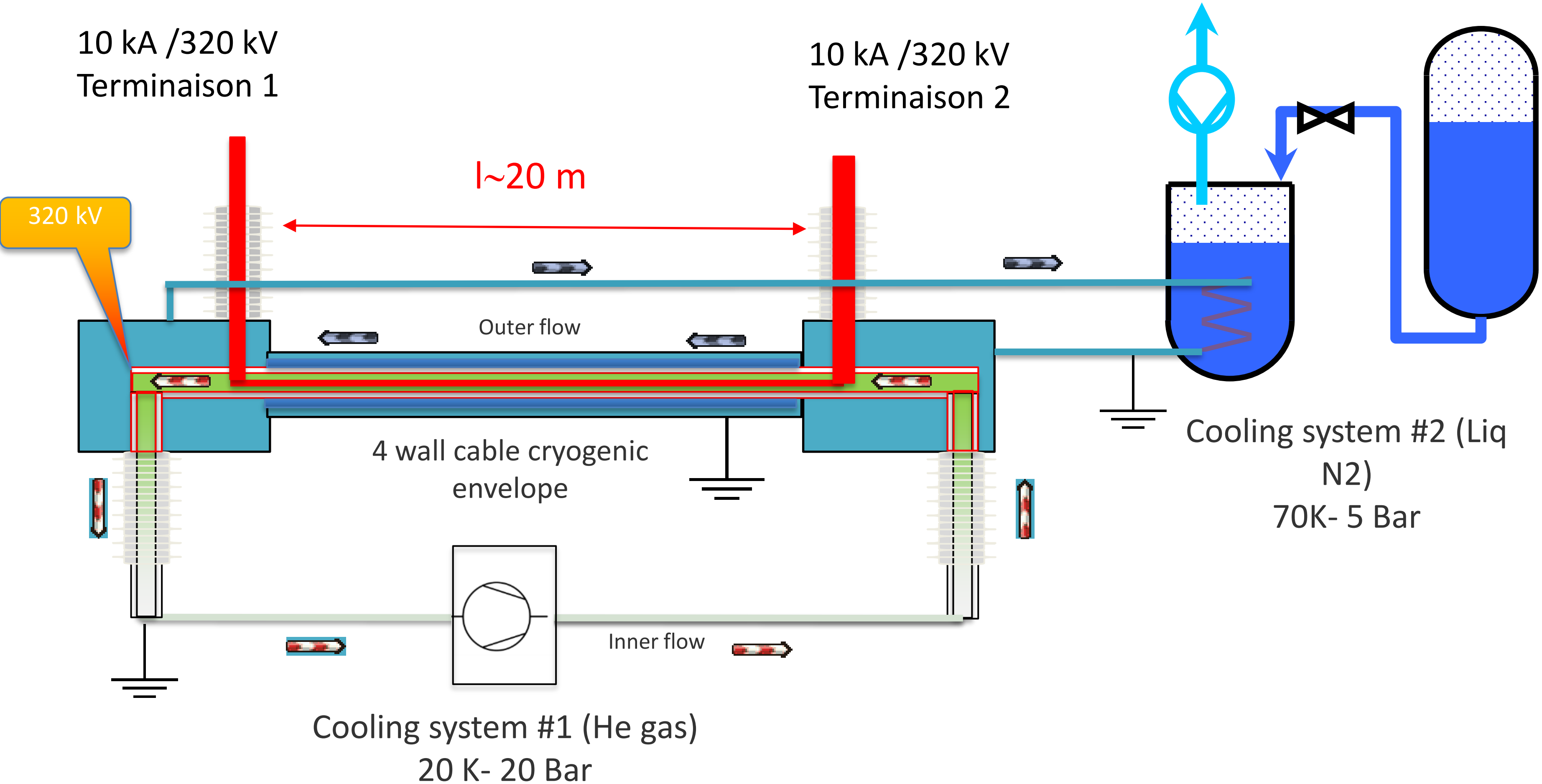


BEST PATHS CABLE LAYOUT

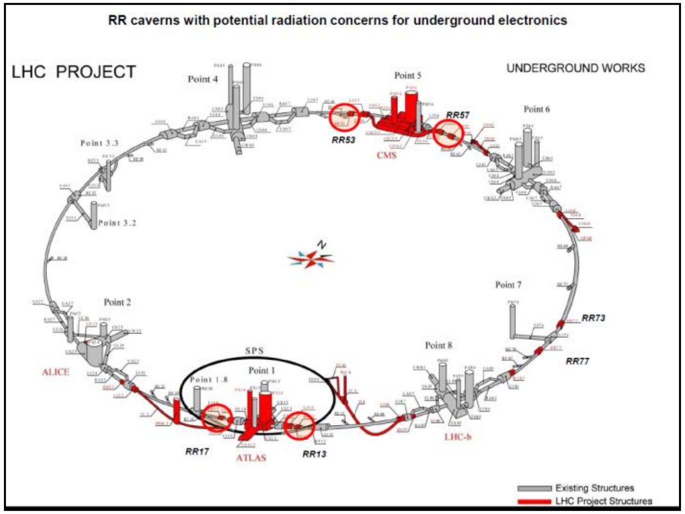


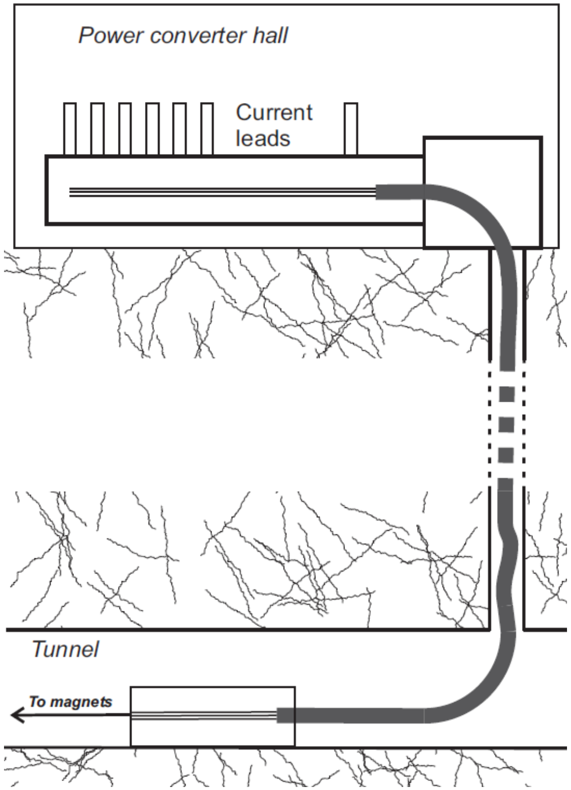
Best Paths project: testing installation

Principle of the testing installation with 2 parallel cooling circuits



SC LINK PROJECT





Development of long superconducting lines for the powering of the LHC magnets via remote power converters

Total currents to be transferred: up to ~ 190 kA per line

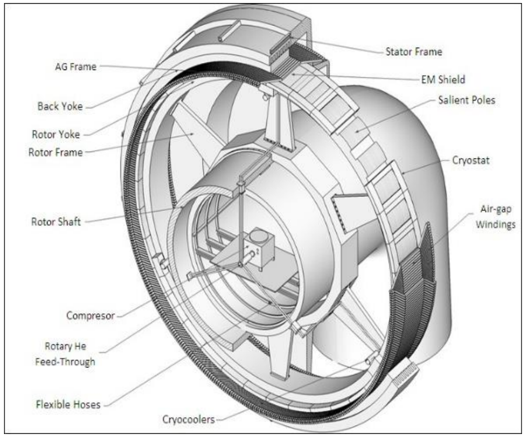
Length: from a minimum of 150 m to a maximum of about 600 m with a significant vertical transfer for the locations where the power converters are to be located at the surface

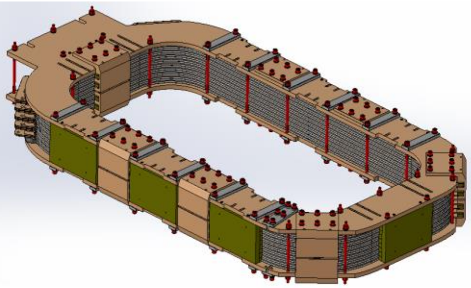
POWER DEVICES (DEMO PROJECT)

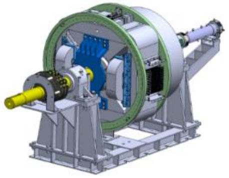
- Successful test of the 36 kV **FCL** took place at IPH - Berlin
- Two coils each based on 25 km-long wires are DC powered, and have the purpose of saturating several iron yokes
- This FCL is in discussion to protect a substation in the Italian grid for installation in 2019

suprapower

Superconducting light generator for large offshore wind turbines





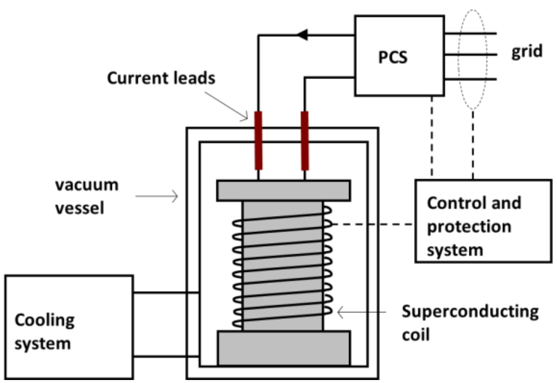


COLLABORATIVE PROJECT

DRYSMES4GRID

Superconducting Energy Storage for Smart Electrical Grid

- To demonstrate the feasibility of SMES
  - 500KJ/200KW
  - Cooling without using cryogenic liquid
- To evaluate the technical and economical benefit that a SMES can bring to the real world network

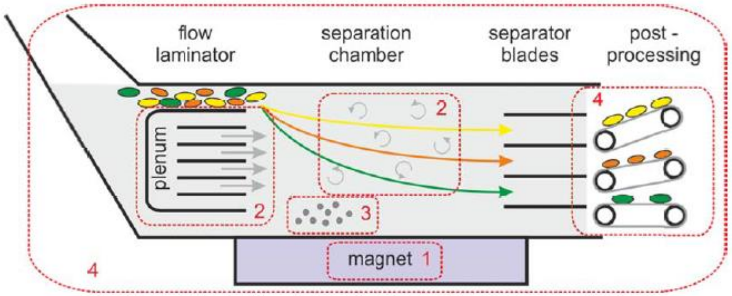


NWO Applied and Engineering Sciences

STW Perspectief

Perspectiefronde 2014/2015 - Fase 3: Programmavoorstel

Innovative Magnetic Density Separation for the optimal use of resources and energy



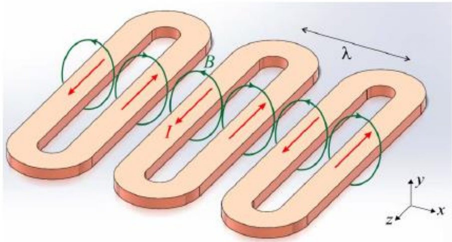
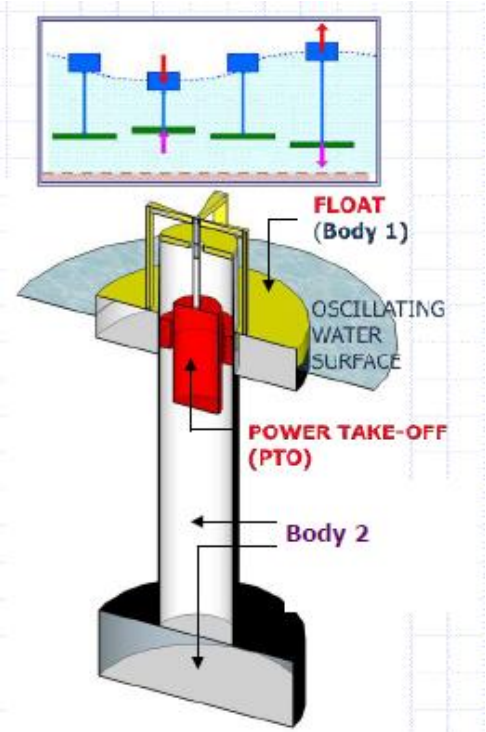
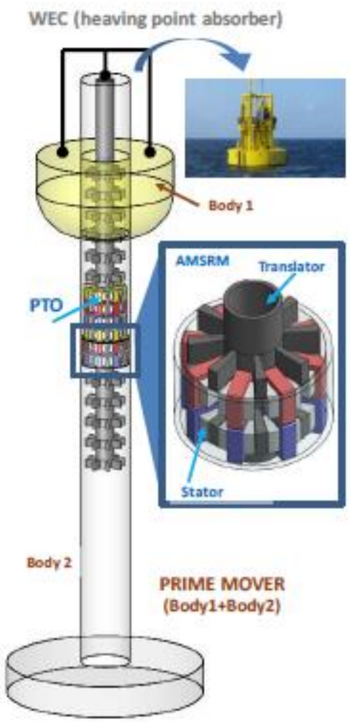


Figure 1: schematic lay-out of the superconducting coil system.

IMPROVEMENT OF THE EFFICIENCY IN A PTO (POWER TAKE-OFF) FOR WAVE ENERGY CONVERTER





Participant Organization name	Acronym	Country
Wedge Global S.L.	WEDGE	Spain
CIEMAT	CIEMAT	Spain
WavEC - Offshore Renewables	WavEC	Portugal
CorPower Ocean	CORPOWER	Sweden
Centipod LTD	CENTIPOD	UK
Hydrocap Energy SAS	HYDROCAP	France
OCEM Energy Technology srl	OCEM	Italy
Columbus Superconductors	CLBS	Italy
Engie - Cofely Fabricom	ENGIE	Belgium
EDP Centre for New Energy Technologies	EDP CNET	Portugal
Asociación Española de Normalización	UNE	Spain