Present status of MgB_2 wire manufacturing

29th November 2012

Columbus Superconductors

Summary

- Why MgB_2
- Where we are today at Columbus
- What we are producing
- For what we are producing
- Hopes for the near future

MgB_2

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Superconductivity at 39 K in magnesium diboride

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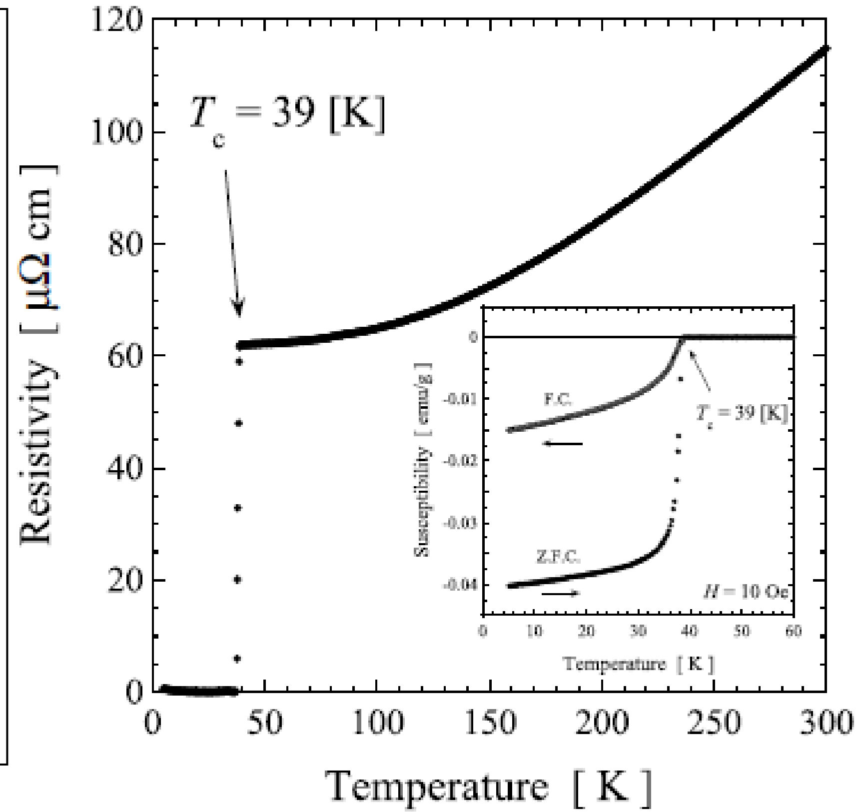


MgB_2 has opened a new frontier in the physical properties and application of SC

The limit of Tc in metallic superconductors was considered equal to 30 K and this unexpected discovery of high Tc in this simple binary intermetallic compound has caused huge interest around the world

Superconductors

Low Temperature Superconductors

- Nb – NbTi – Nb_3Sn
- Produced from the seventies
- Low price (1-10 €/m)
- Operable mainly in Liquid Helium
- Commodity – 5-10 companies competing with similar products and know-how
- Mostly employed in MRI/NMR and 'big physics'
- Revenues derived : 4 B€/anno

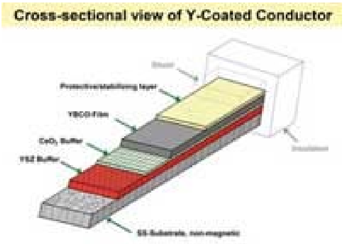
High Temperature Superconductors

- Bi-2223 (1G) – YBCO-123 (2G)
- Produced from the nineties
- Higher price (10-100 €/m)
- Operable also in liquid nitrogen
- R&D – 5-10 companies active
- Commercial outcomes somewhat limited so far by cost/difficulty of the proecessing

MgB_2

- Discovered as SC in 2001
- Low cost (1-10 €/m)
- Operable up to 30K
- Product already matured– 5 companies active
- Commercial outcomes achieved

Which superconducting solutions are available today?

	MgB_2	BSCCO	YBCO
Wire type	 Round wire or tape with SS sheath	 Silver sheathed tape	 Thin film on metallic substrate with biaxial texture
T_c (K)	39 K	108 K	90 K
Current carrying capability at 20 K	1000 A	1000 A	1000 A
Superconducting splices	**YES**	NO	NOT YET
Low cost (< 5 $/m)	**YES**	NO	NOT YET (likely within 5 years)
Long lengths (>5 Km)	**YES**	NO	NOT YET (likely within 5 years)

Columbus Superconductors

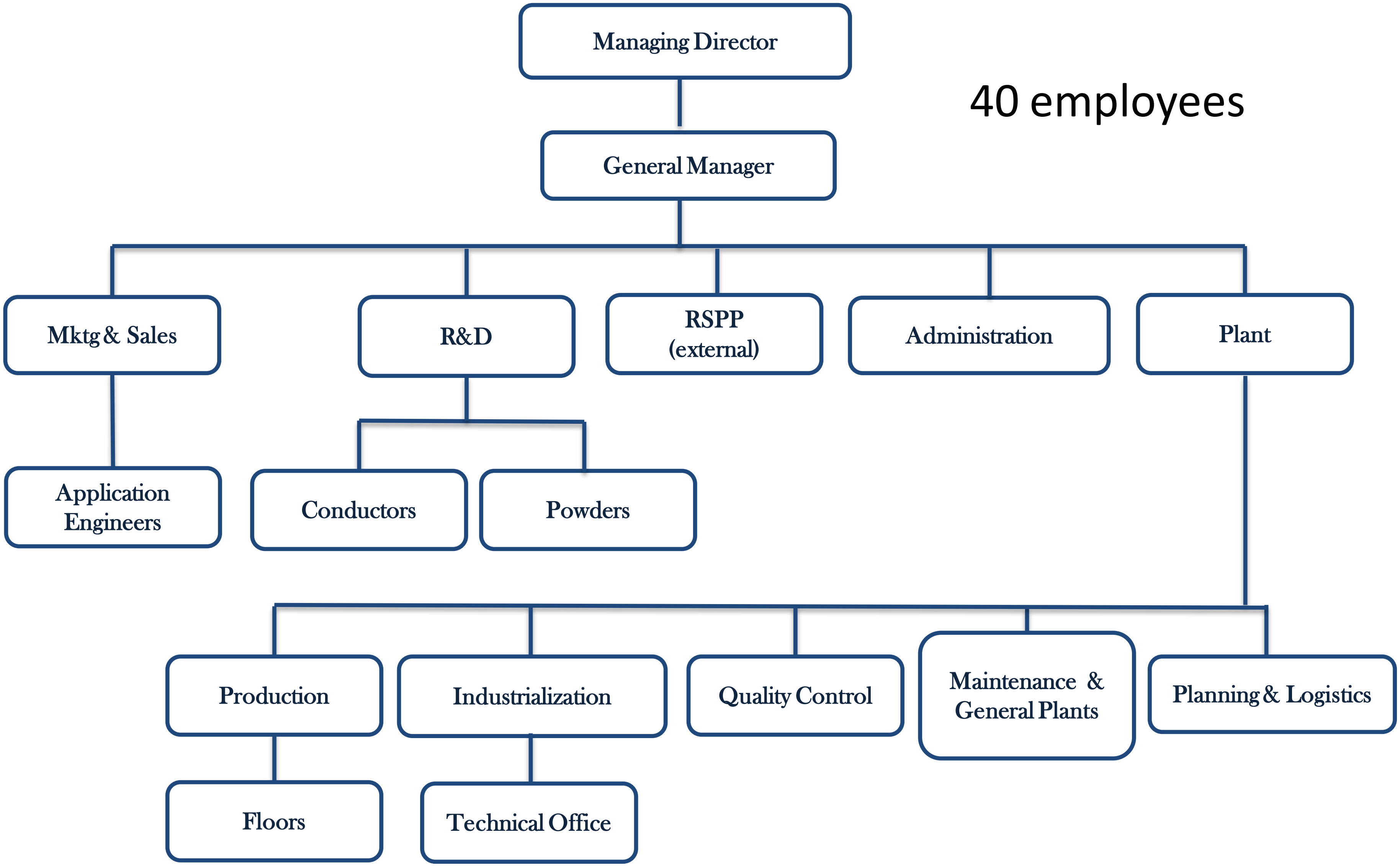
The Company

Columbus has been founded in 2003 as a **start-up** originated from the Italian National Research Council **(CNR)**

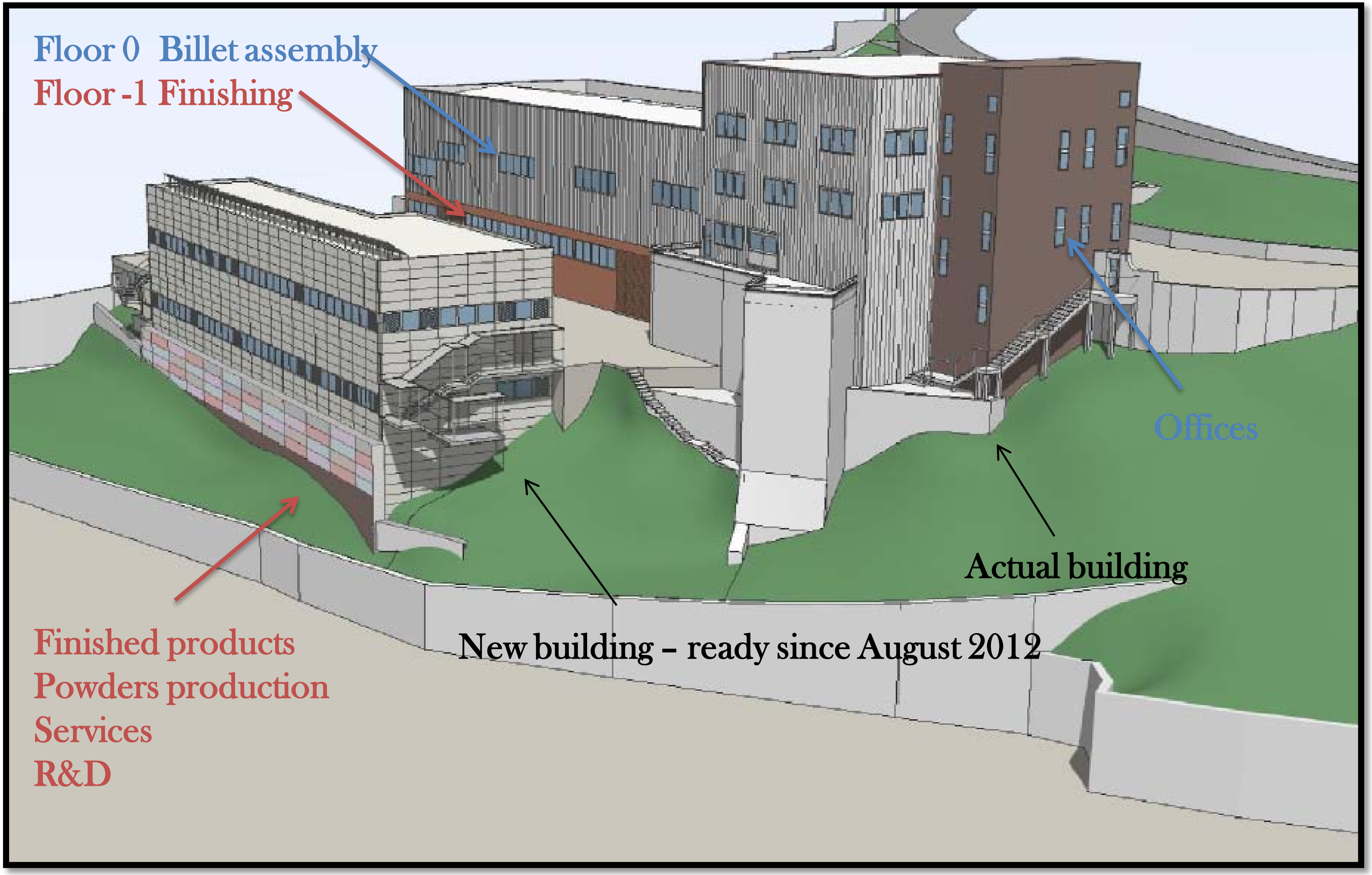
- The actual plant is fully operational for **MgB_2 wire production** and is completing scaling up
- **MgB_2 compound production** is now also fully implemented
- Wire unit length today up to **2- 4 Km in a single piece –length**
- It is scaled up to **20 Km** together with the full scale up of the plant with capacity exceeding **4'000 Km/year**
- Columbus **MgB_2 production for MRI** has exceeded **700 Km** of fully tested and qualified wires
- Total plant area **4'400 m^2** after being increased by further **1'000 m^2 in September 2012**

Organization Chart

40 employees



Scaling Up (1)


Floor 0 Billet assembly
Floor -1 Finishing
Offices
Actual building
New building – ready since August 2012
Finished products
Powders production
Services
R&D

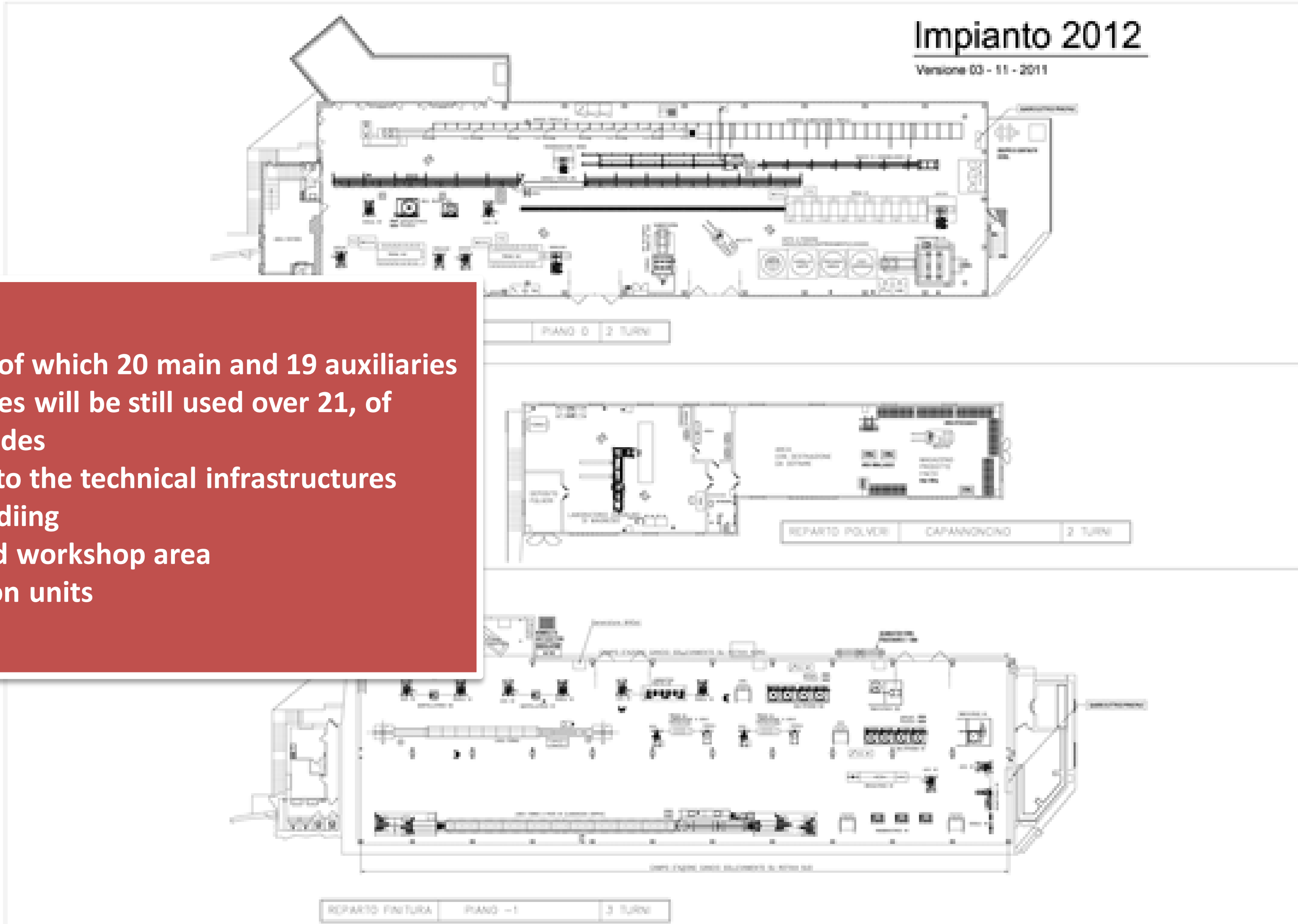
Columbus Superconductors plant







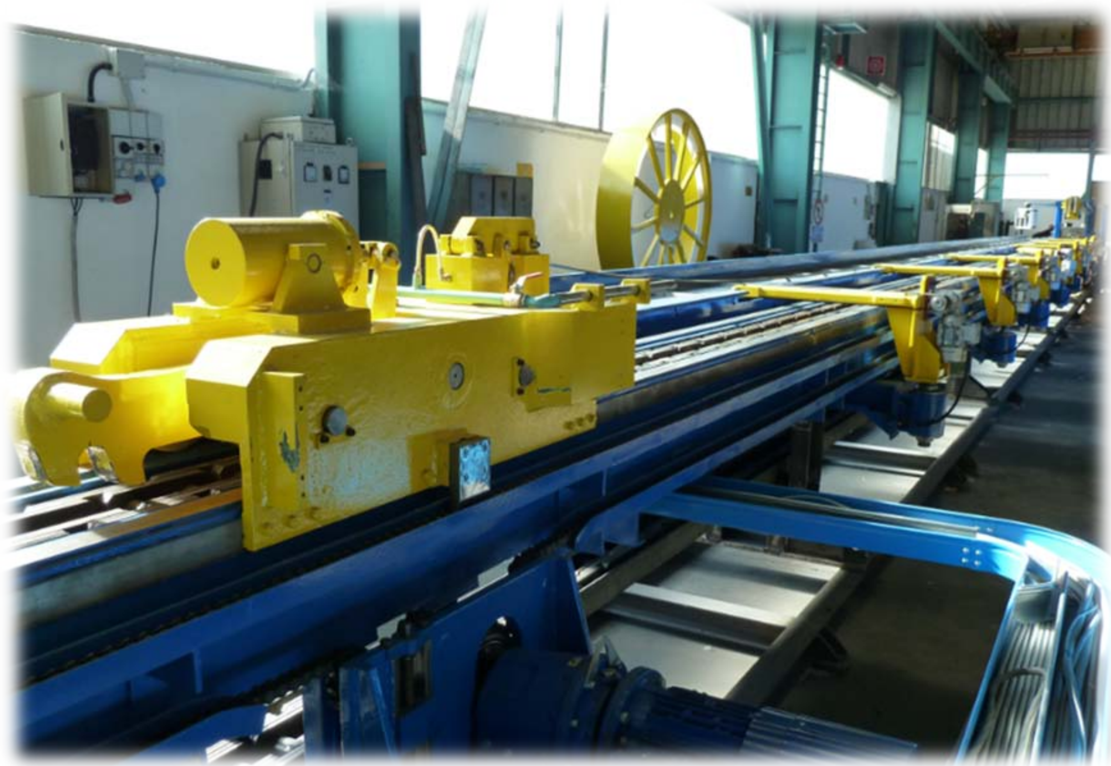

Expansion of our production



- 39 new machines, of which 20 main and 19 auxiliaries
- 15 existing machines will be still used over 21, of which 9 need upgrades
- 10 main upgrades to the technical infrastructures
- 1 new 2 floors buildiing
- 2.280m² of covered workshop area
- 20 direct production units

PHOTOGALLERY
CLEAN SYNTHESIS OF MgB_2

PHOTOGALLERY
HIGH POWER STRAIGHT BENCH N1



PHOTOGALLERY
MULTISTEP DRAWING N1 & N2

PHOTOGALLERY
20-METER LONG IN-LINE FURNACE

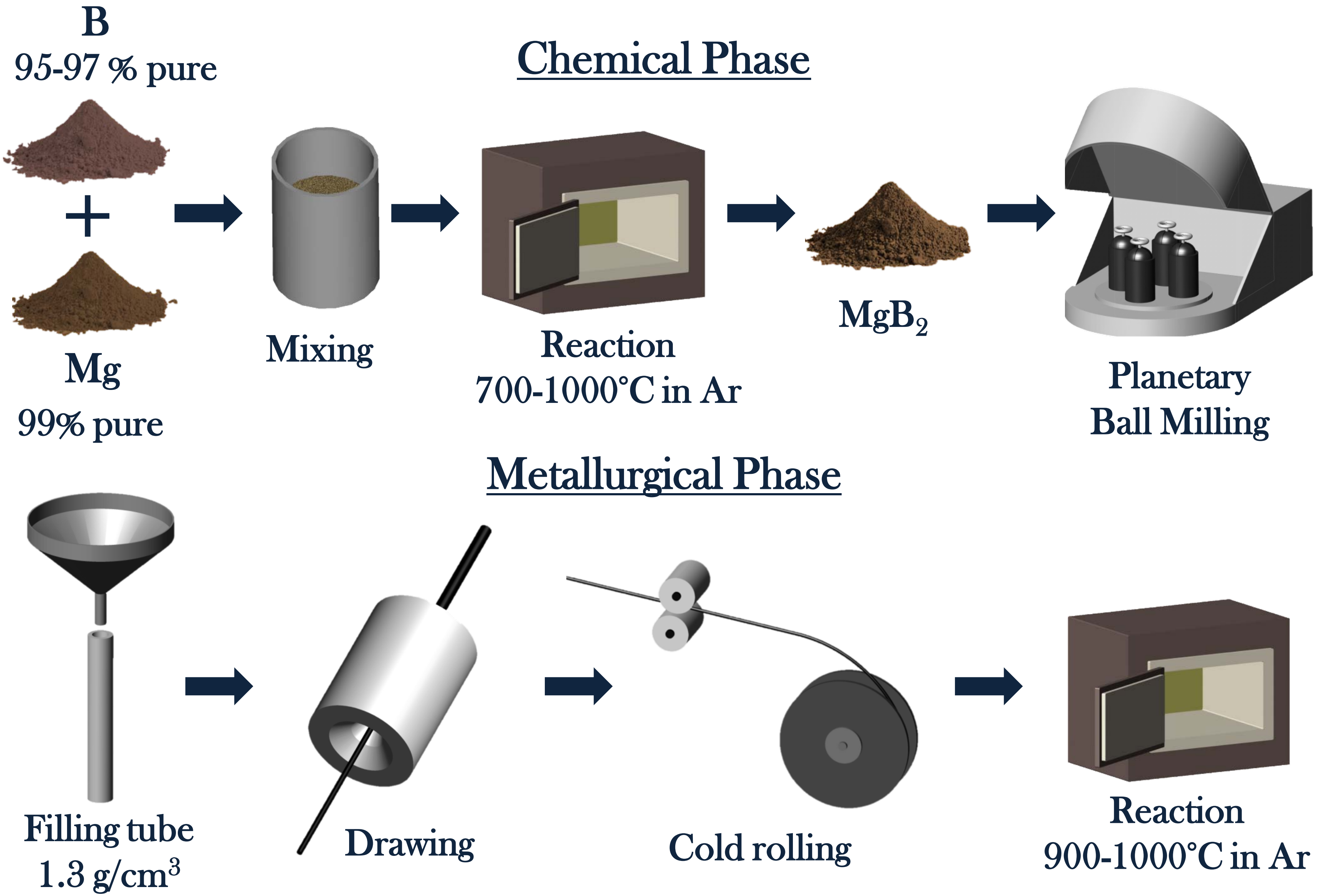
PHOTOGALLERY
4-METER FURNACE FOR WIRE ANNEALING N1

PHOTOGALLERY
THREE LARGE ROLLING MILLS

Quality control methods we are implementing

- Hitachi SEM with EDX
- Bruker ultra fast XRD
- Fritsch Analisette 22 laser particle size analyzer
- Forster radiofrequency defect detector
- Optical stereomicroscopes
- Laser wire size and shape online monitor
- Industrial video cameras for surface defect detection
- Additional cryo-free critical current testing system under construction

Production Process

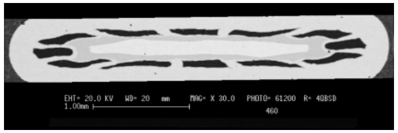


Wire Design : State-of-the -Art

There are **3 different wire formats:** Round, Flat and Sandwich

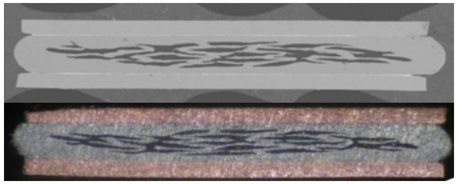
Flat tape

- The flat tape architecture has been the work-horse for Columbus in the past years and it has been the preliminary choice of our customers to start to understand the potential of our material
- Flat tape conductor is mainly used in small bore magnets and low current devices



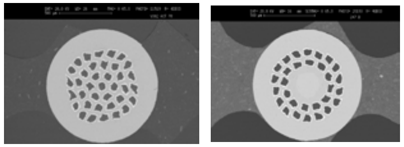
Sandwich conductor

- This architecture is our solution for future magnet and winding applications
- It allows the maximum flexibility in the control of the wire absolute performance and in the amount of Cu stabilization
- Being the Cu stabilizer not subjected to the thermomechanical treatment of the MgB_2 conductor, it's soldered to it in its optimal mechanical and electrical condition



Round wire

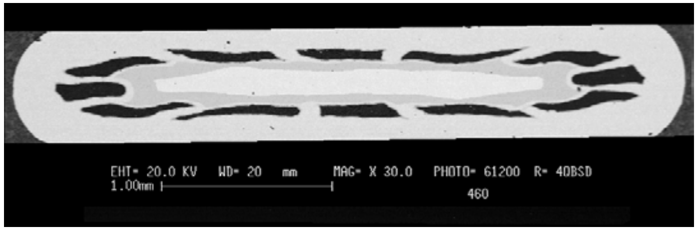
- MgB_2 is currently the only no low-Tc superconductor that can be easily produced in round wire shape with significant transport properties, multifilamentary structure and excellent reliability over long lengths
- Round wires present several advantages, particularly concerning easier solenoid and more complex magnet winding, and absence of anisotropy

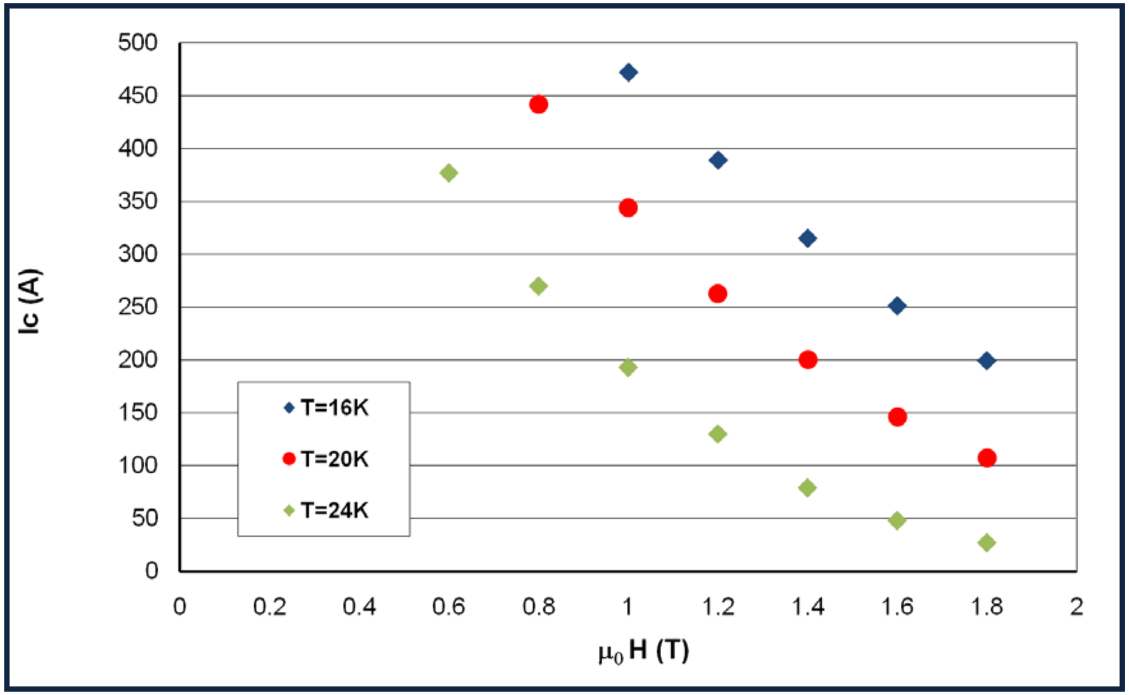


Wire Design : Flat Tape

Outer sheath of Nickel surrounding 12 MgB_2 filaments protected by a Nickel barrier and stabilized with Copper core with Iron barrier

The unit piece is already 1,6 Km



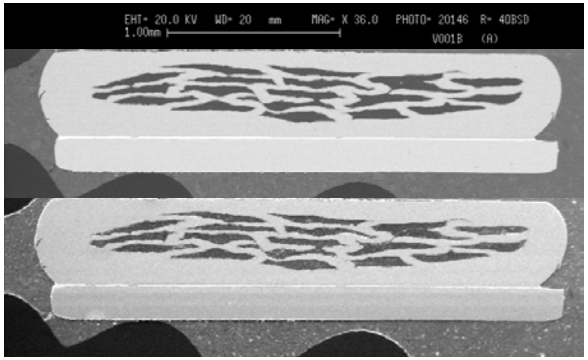


Material	Area (mm^2)	%
MgB_2	0.33	14
Ni	1.45	61
Iron	0.23	10
Copper	0.36	15
Total	2.37	100
Dimension	**3.5 x 0.65**	

Wire Design : Sandwich Conductor

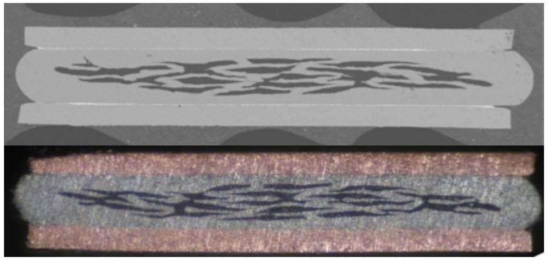
Outer sheath of Nickel surrounding 19 MgB_2 filaments protected by a Nickel barrier and Copper external stabilization

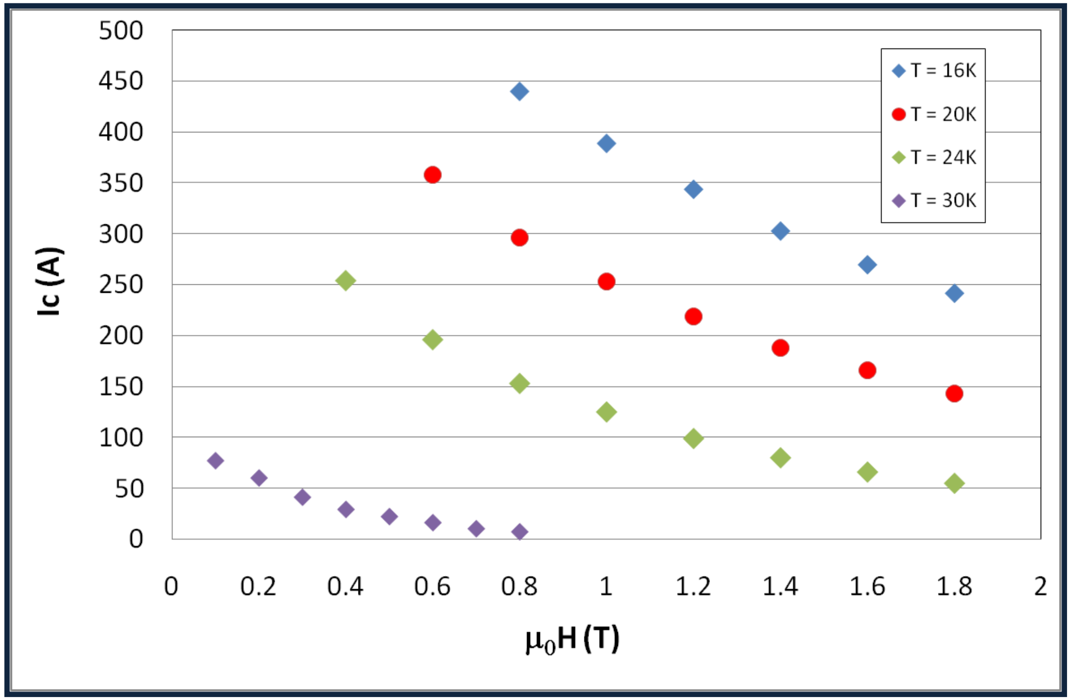
The unit piece is already 2,5 Km. The scaling up of the production process will lead to a 15 Km unit piece length



- The data reported in the figure below are relative to a conductor optimized for 10 K behaviour, i.e., with some light **C doping**
- Because the C doping is slightly depressing the Tc, data are not representing the best conductor for use at about 20 K

Material	Area (mm^2)	%
MgB_2	0.36	24.1
Ni	1.14	75.9
Total	1.5	100
Dimension	**3.0 x 0.5**	
Copper	0.6	
Dimension	**3.0 x 0.2**	



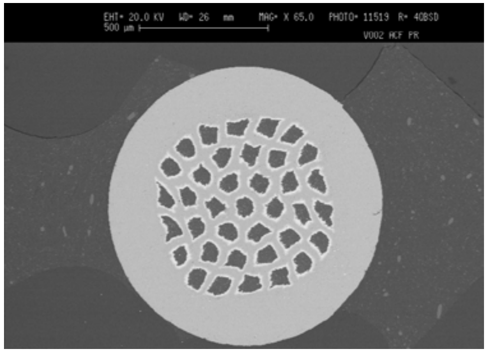


Wire Design : Round Wire

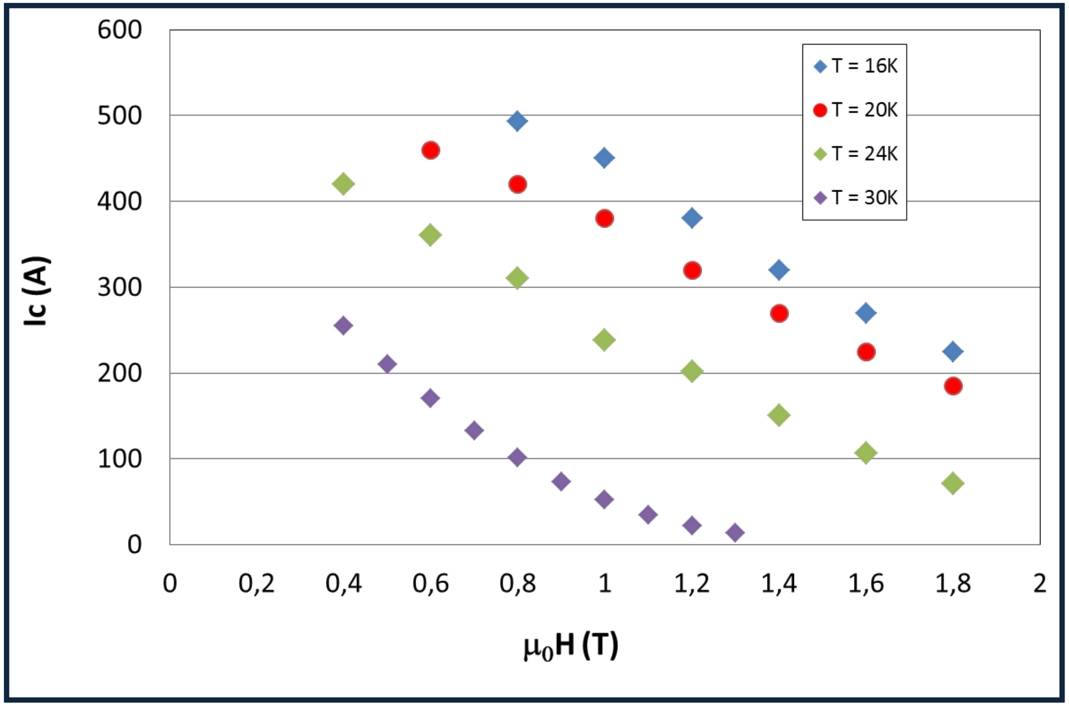
Outer sheath of Monel 400 surrounding 37 MgB2 filaments protected by a Nb barrier and embedded in a Ni 201 alloy matrix

The unit piece is already 3,5 Km.

The scaling up will lead to a 20 Km unit piece length



Material	Area (mm^2)	%
MgB_2	0.16	16.5
Nb	0.15	14.6
Ni	0.16	15.5
Monel	0.53	53.4
Copper		
Total	1.00	100
Diameter	**1.13**	



Practical Applications

- **MEDICAL FIELD**

  Cooperation between Columbus, ASG and Paramed has brought to life a new generation of cryogen-free, "open-sky" MRI system. Use of MgB_2-based magnets bypasses the need of a cryogenic coolant, reducing encumbrance, servicing cost and refill time

- **ENERGY PRODUCTION**

  Superconducting motors and generators, especially into hydroelectric and wind energy field, to improve efficiency and reduce encumbrance and weight

- **POWER QUALITY & STORAGE**

  SFCL for a more protected network and SMES to make the distribution of energy generated by alternative sources more stable over time

- **TRANSPORTATION**

  Marine Superconducting Motors, which allows for a considerable improvement from both the weight and efficiency point of view

- **HIGH ENERGY PHYSICS**

  Superconducting magnets for particle accelerator and nuclear fusion experiments mean power saving and dimension reduction of the facilities, together with great efficiency improvement

The MRI system MROpen

MROpen has been developed employing the flat tape architecture

MRopen

Columbus Superconductors

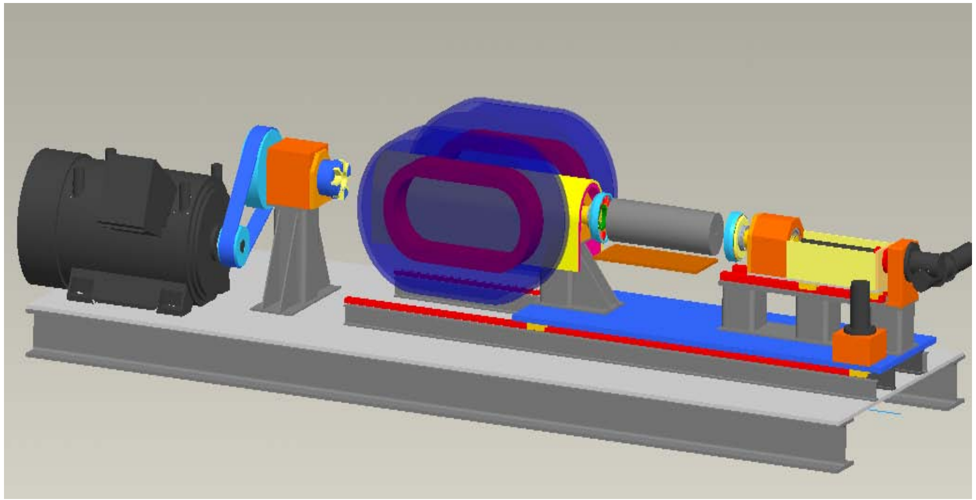
ASG Superconductors

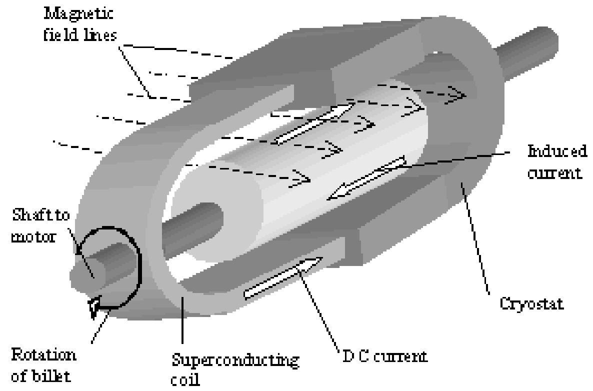
PARAmed MEDICAL SYSTEMS

First commercial systems already installed and fully operational in hospitals and private clinics in EU and North America

- Unique **fully dry** superconducting **MRI** system currently **on the market**
- Based on Columbus **MgB_2** technology
- Unique superconducting **open-sky MRI** system currently on the market
- Very attractive because of its features (scanning **with/no load**, children, **no claustrophobia**, very easy installation and running, ..)
- More than a **dozen systems** produced **so far**
- Also highly **suitable for remote installation** because electricity is the only requirement to setup/start/run the system – **not suffering** from scattered **power outages** though

DC Induction Heater development





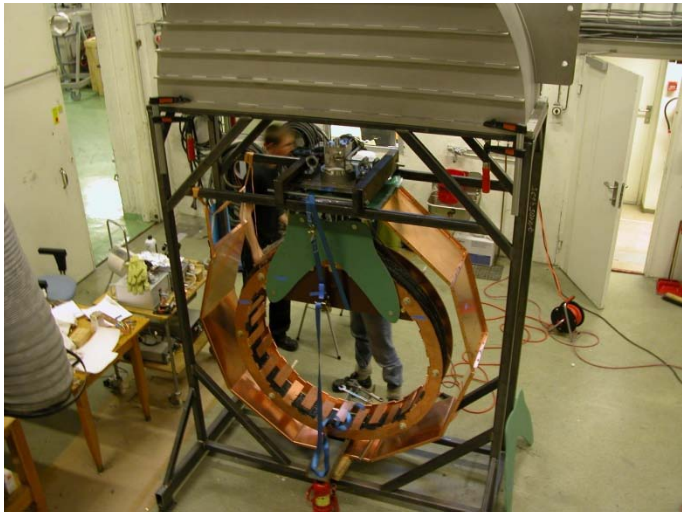
η=90%

Objectives of the ALUHEAT project are:

• To **validate** from a technical and economical point of view a new concept by building a 200-300 kW **aluminium billet induction heater** and test it in an industrial aluminium extrusion plant

•To **dramatically reduce energy consumption and life-cycle costs** in one of the large-scale electrotechnical components with poorest energy efficiency and at the same time **improve** the production quality

•The **magnet** uses about **20 Km of MgB_2** wires, and it has been **successfully tested** at design specs (200A, about 2 Tesla)



System under advanced testing at TUT University laboratory in Finland, with SINTEF - Trondheim

Advantages of a superconducting generator (1)

Failures of gearboxes have been reducing the reliability of offshore turbines and there have been a trend in the industry towards omitting the gearbox, introducing direct drive technologies based on copper field windings or permanent magnets

However, the usage of the magnets based on rare earth elements is of the order of 600 Kg/MW and will impose a considerable increase in the worldwide demande. China is producing 95% of the rare earth elements and has imposed export quotas

Conventional Turbine Generator

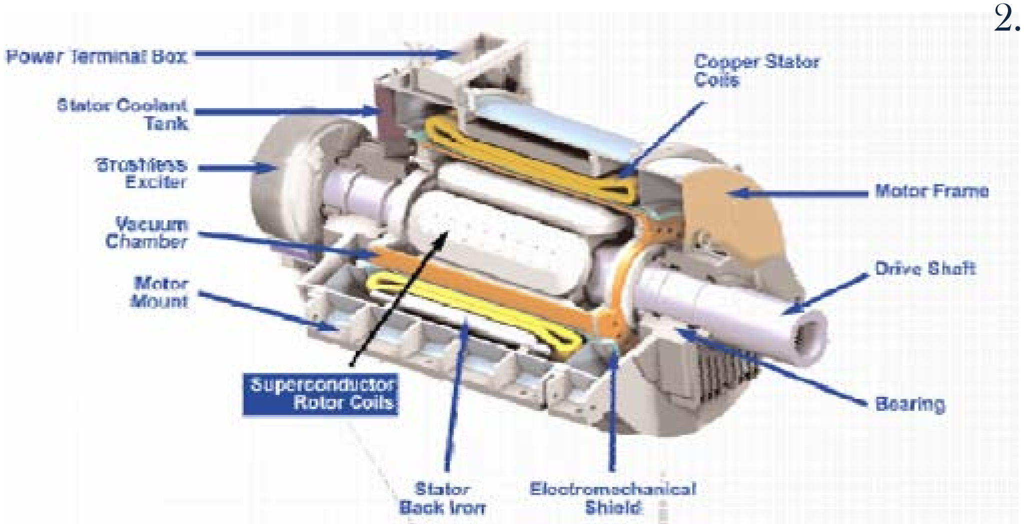
Copper Wound Coil with Gearbox
> 500 t

Permanent Magnet No Gearbox

PM
< 320 t

Superconducting Generators

- could offer several cost and reliability improvements over conventional wind turbine drivetrains when scaled up to high capacity (5 MW and larger) and when used in direct drive systems: they do not require a gearbox
- less mass and less volume than PM generators, resulting in an overall reduction in turbine capital costs
- cost advantages produced by such weight savings are most likely to be realized initially in large turbines
- should increase drivetrain reliability by allowing a larger air gap tolerance between rotor and stator as compared to PM generators
- hold the potential of providing high torques in a smaller size and with smaller weight than conventional technologies, but there are two critical points:
  1. demonstrate the reliability of the technology
  2. choose superconducting wires with a low price



Superconducting Generators
150 t

Boost to our MgB_2 technology

- Two large frontier projects will help boost our production and quality in the upcoming years
- Cern and the fusion community are implementing MgB_2 critical components in their devices in order to profit from the high operating temperature of the superconductor, and the high current carrying capability without incurring in the extra costs and technical risks of complex and delicate HTS materials

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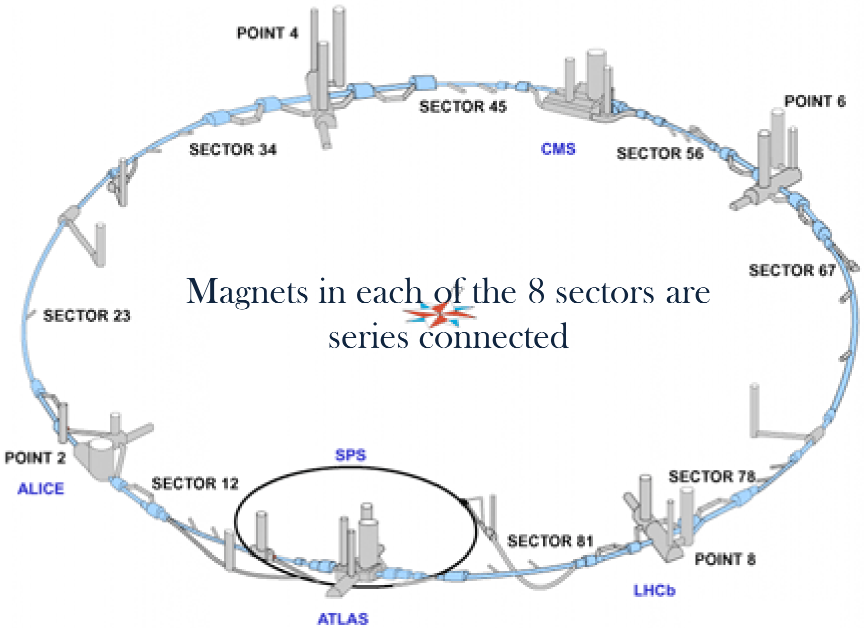
Boost 1: MgB_2 conductors for powering cables

Cold powering of CERN LHC magnets using superconducting cables

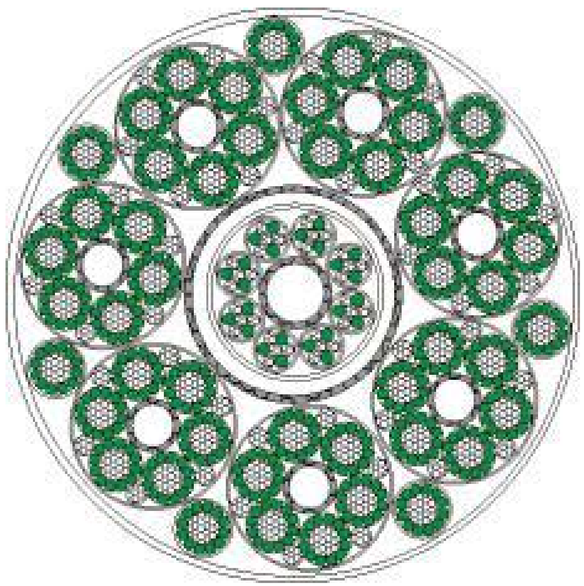
Current has to be fed to a number of different magnet types

Total current to be fed in each sector is about 220 kA

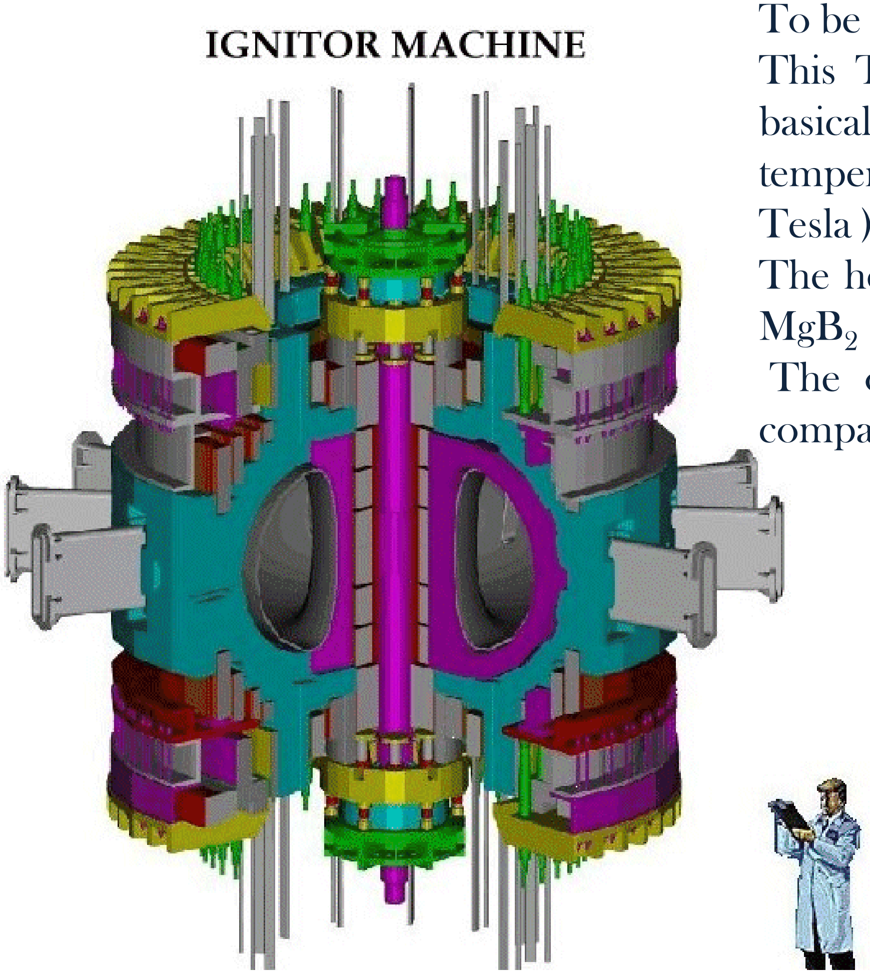


Magnets in each of the 8 sectors are series connected

Problem to be addressed: reliability of the magnets feed boxes placed in the tunnel that need constant maintenance while becoming heavily radioactive – moving them to the power supply caves far from the beam



Boost 2: the IGNITOR nuclear fusion project



To be installed in Russia within a close partnership with Italy

This Tokamak is very compact (about 6 m diameter), and basically consists of resistive Copper coils cooled to cryogenic temperatures, due to the extremely high magnetic field (>> 20 Tesla), and operated in quasi-pulsed mode.

The helium gas cooling technology compatible with the use of MgB_2

The outer poloidal field coils experience a field which is compatible with today's MgB_2

Why MgB_2 in this machine?

To prove feasibility of future nuclear fusion systems with much higher duty cycle

MgB_2 cable for outer poloidal field coils

J_{cs} of a single MgB_2 strand @ 4T, 15K	1000 A/mm^2
Superconducting filling factor	20%
Single Strand diameter	1mm
Total cross section	0.784mm^2
SC cross section in a single strand	0.784*0.2= 0.15 mm^2
I_c of a single MgB_2 strand @ 4T, 15K	0.15*1000= 152 A
Number of strand to have 35kA	35000A/152A=230
Total amount of wire	> 500 Km per coil

Summary

- MgB_2 development and production is progressing well
- We believe that MgB_2 cables will represent a very important development for our products
- Dedicated MRI projects are ongoing in several countries
- Total body MRI companies are also starting the implementation of MgB_2 in future commercial systems in order to move to cryogenic-free systems
- New industrial products and research related applications will further help to boost MgB_2 production

Thanks for your attention

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