IASS Advisory Committee on

Long Distance Energy transport with SC lines

(Short introductory remarks)

Carlo Rubbia

November 29th, 2012

Programme of the day

- **Initial presentations**
  - *Amalia Ballarino:* Recent progress on the high-current testing facility for superconducting cables at CERN.
  - *Giovanni Grasso*: Present status of MgB_2 wire manufacturing
  - *Frédéric Lesur*: The perspective of a transmission system operator: A comparison between underground HVDC cables and MgB_2 superconducting cables
  - *Alexander Chervyakov, Adela Marian and Heiko Thomas* : Socio-economic aspects of high-power long-distance direct current superconducting power lines
- **Round-table discussions.**

Main purposes of the IASS study

- A study has been initiated early in 2011 in order to study the feasibility of long distance high power superconducting transport specifically — but not only for renewable energies.
- The largest superconductor system currently available—LHC, HERA, Tevatron, RICH and planned ITER — and how their technical experience gained may become of use for SC power transmission systems.
- Technical and socio-economic constraints and comparative costs of SC, for instance with respect to conventional HVDC systems. Optimisation of transmitted power versus cost. Study of very-high power SC systems whereby cost may become more competitive as compared to HVDC systems.
- Comparison with overhead lines and cables in densely populated areas, in view of the new window of opportunity offered by the new SC materials, especially MgB_2.

Long-distance energy transport with superconducting lines ?

- Remote renewable energy sources require an efficient transfer of electrical energy over long distances.
- High power lines may have lengths of more than 4000 km

First kick-off meeting in 2011

May 12th-13th, 2011

40 participants from academia, research institutions, and industry

Creation of the International Advisory Committee

Kick-off meeting: 29 November 2012

Industry/Utilities/Associations (6)

1. Nexans - France
2. RTE - France
3. Bruker HTS GmbH - Germany
4. Asea Brown Boveri (ABB) - Germany
5. RWE - Germany
6. Industrieverband Supraleitung - Germany

(6)

Research Institutions (5)

1. Center of Applied Superconductivity and Sustainable Energy Research,Chubu University, Japan
2. Electric Power Research Institute (EPRI), USA
3. Institute of Electrical Engineering, CAS, China
4. Russian Superconducting Institute,Moscow, Russia
5. W2AGZ Technologies, USA

Socio-Economic (3)

1. DIW- Berlin, Germany
2. IIASA,Vienna,Austria
3. Industrieverband Supraleitung - Germany

Members of the International Advisory SC Committee

- **Carlo Rubbia**, IASS Scientific Director (Convener)
- **Andreas Breuer**, Coordinator New Technologies and Projects, RWE Deutschland AG
- **Reinhard Dietrich**, Managing Director, Bruker HTS GmbH, Germany
- **Steve Eckroad**, Electric Power Research Institute (EPRI), USA
- **Paul Grant**, W2AGZ Technologies, USA
- **Claudia Kemfert**, Director, Transport, Energy and Environment, DIW- Berlin, Germany
- **Jochen Kreusel**, Head of Smart Grids Programme, Asea Brown Boveri Ltd (ABB)
- **Frédéric Lesur**, Centre National d'Expertise Réseaux, Réseau de transport d'électricité (RTE), France
- **Nebojsa Nakicenovic,** Deputy Director,IIASA,Vienna,Austria
- **Werner Prusseit**, President, Industrieverband Supraleitung, Germany
- **Jean-Maxime Saugrain**, Corporate Vice-President Technical, Nexans, France
- **Vitaly Vysotsky**, Head, Russian Scientific R&D Cable Institute,Moscow, Russia
- **Liye Xiao**, Director Institute of Electrical Engineering, CAS, China
- **Satarou Yamaguchi**, Director Center of Applied Superconductivity and Sustainable Energy Research Electrical and Electronic Engineering, Chubu University, Japan

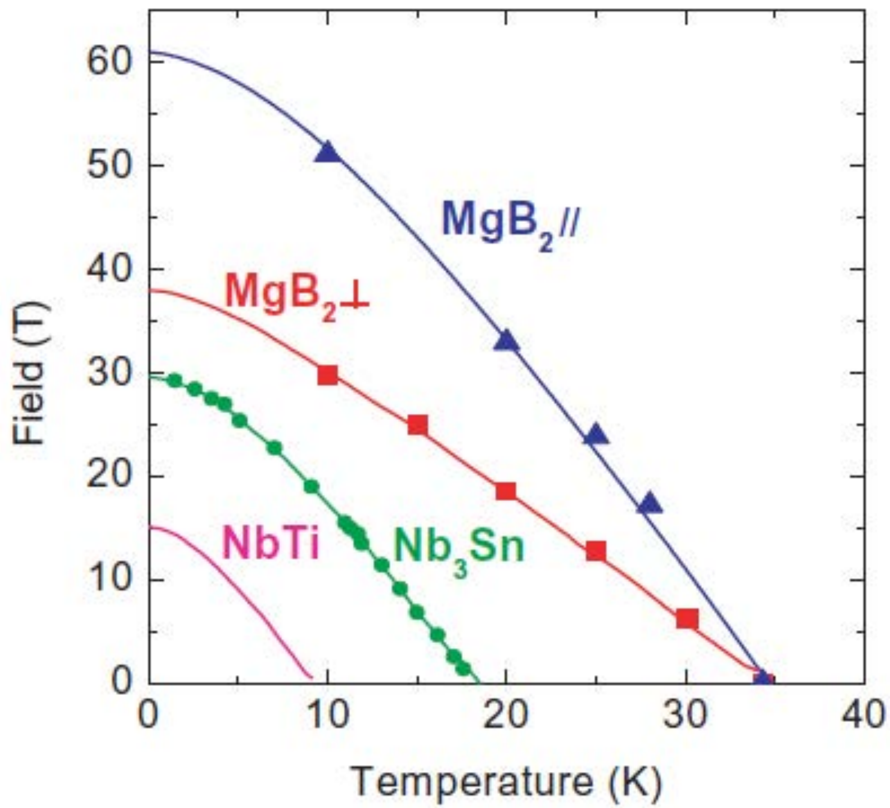
Choices of SC alternatives

- Existing superconducting materials and cryogenic components do not deliver a competitive alternative to existing technologies.
- Both recent progress and ongoing research promise to improve performance and reduce costs so that a competitive parity with conventional transmission is expected in a few years' time.
- *The relatively recent development of MgB_2 superconductor appears as the most desirable solution which may provide a low cost cable and a sufficiently high cryogenic temperature.*

SC Material	*Main Coolant*	*T (K)*	*Thermod factor*	*Cable wire costs*	*kryogenic-complexity*	*cable complexity*
NbTi	liquid He	1.9-4.3	400	low (≈1 kA m)	high	low
HTS	liquid N_2	60-75	9	high (>50 kA m)	low	high
MgB_2	liquid H_2 or gasHe+LN_2	15-20	40	low (<1 kA m)	low	low

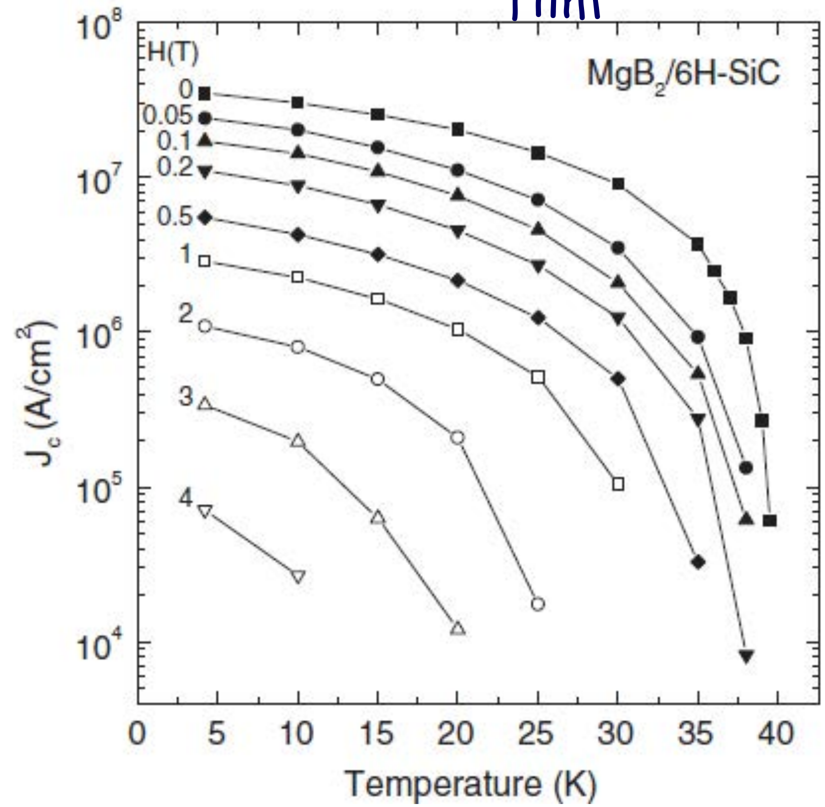
Why MgB_2?

High critical field in thin film



Iwasa Y et al. 2006
A round table discussion on MgB2: towards a wide market or a niche production?
IEEE Trans. Appl. Supercond 16 1457-64

Large critical current density on thin film

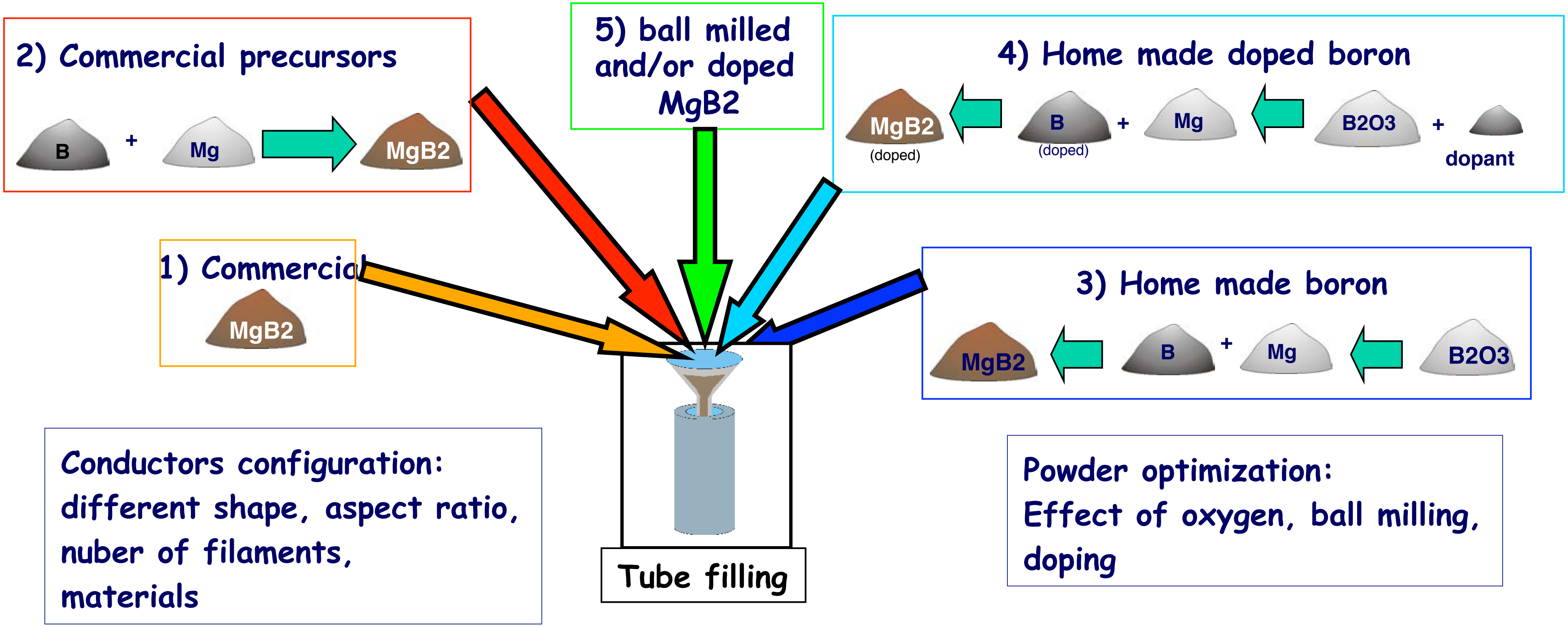


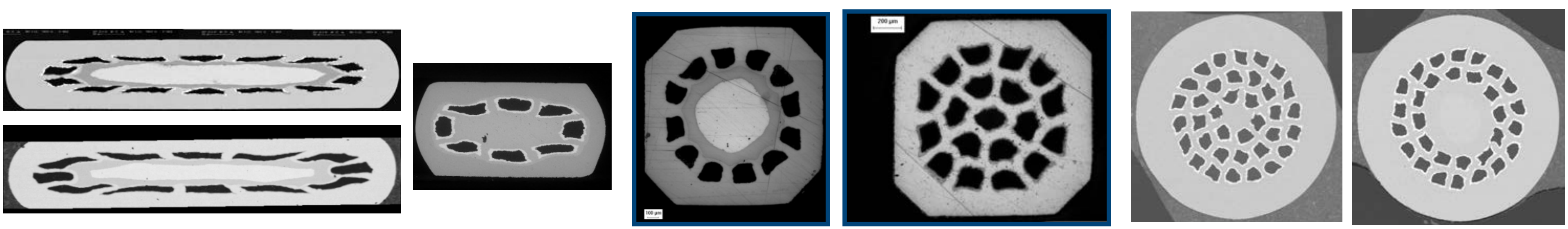
Zeng et al. 2003
Superconducting MgB2 thin film on silicon carbide substrate by HPCVD
APL 82 2097-9

New, promising features of MgB_2

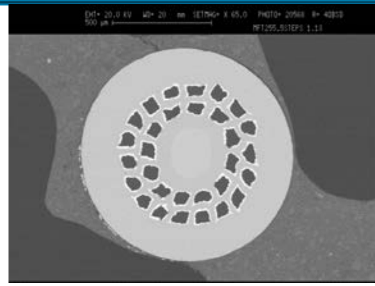
- In January 2001 superconductivity at ≤ 40 K was announced for a simple new compound, the Magnesium Diboride, MgB_2.
- In analogy with Nb-Ti. an extremely simple method of producing Cu stabilized wire and easy production have been demonstrated with abundant and cheap B and Mg of reasonable purities.
- Wire unit length today up to 20 Km in a single piece, easily scalable by increasing billet size/length. More flexibility on design and much lower cost than with HTS.
- SC wire projected in 3 y. at 20 K and 0.8 T to about 0.5 €/kAm.
- Transmission peak powers of many GWatt HVDC are possible, still dominated by power independent cryogenic losses.
- Very long segments of several hundred kms with either He+LN_2 or LH_2 coolants offer small diameters and simple geometries.
- Low density LH_2 at 20 K permits wide altitude differences along the pipeline (δp = 6.7 bar for δz = 1 km)

Columbus process (see next presentation by Gianni Grasso)

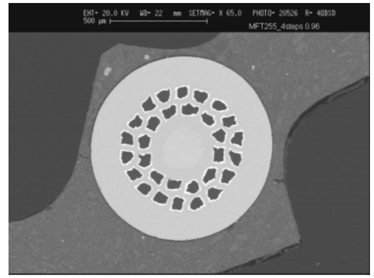




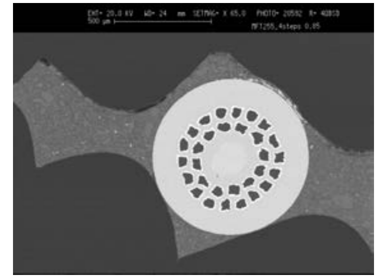
Stabilized round wires down to 0.85 mm



Diameter 1.13mm

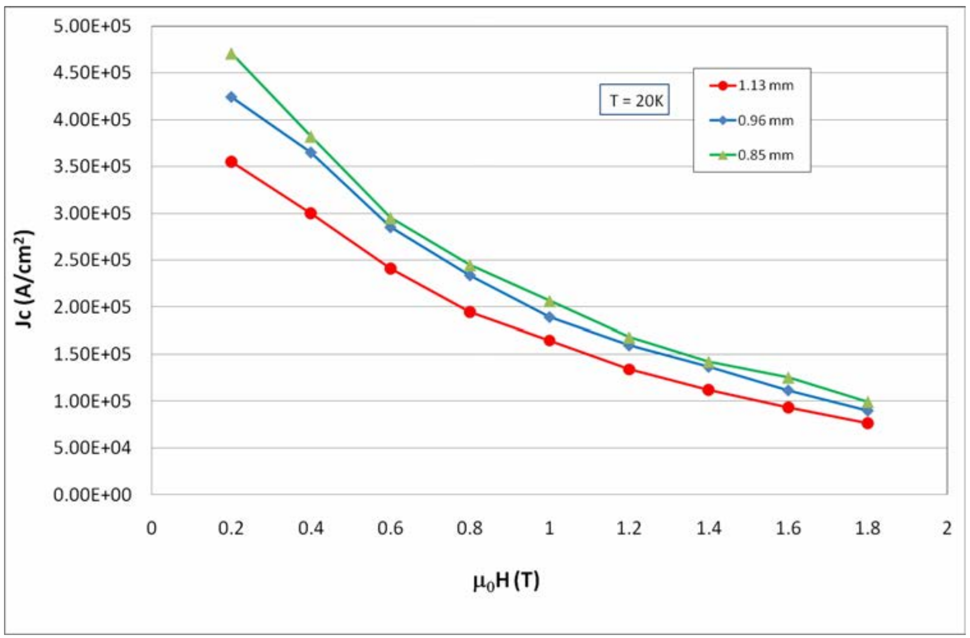


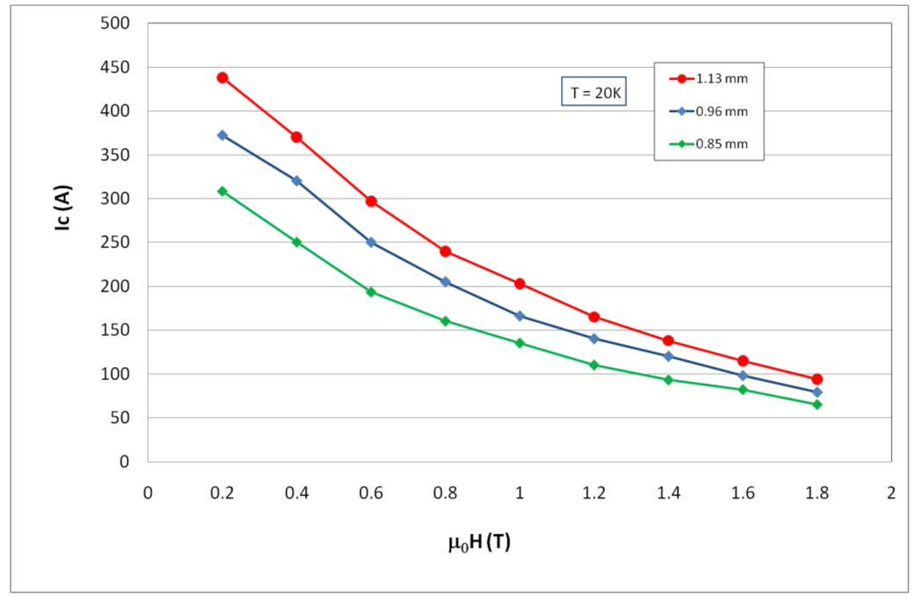
Diameter 0.96mm



Diameter 0.85mm

Critical current densities:
1.13 mm: 1.7 105 A/cm2 @ 20K, 1T
0.85mm: 2.1 105 A/cm2 @ 20K, 1T



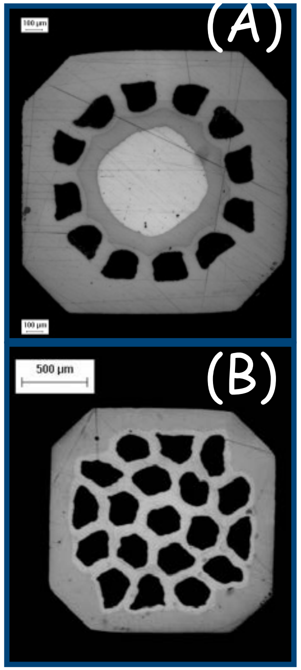


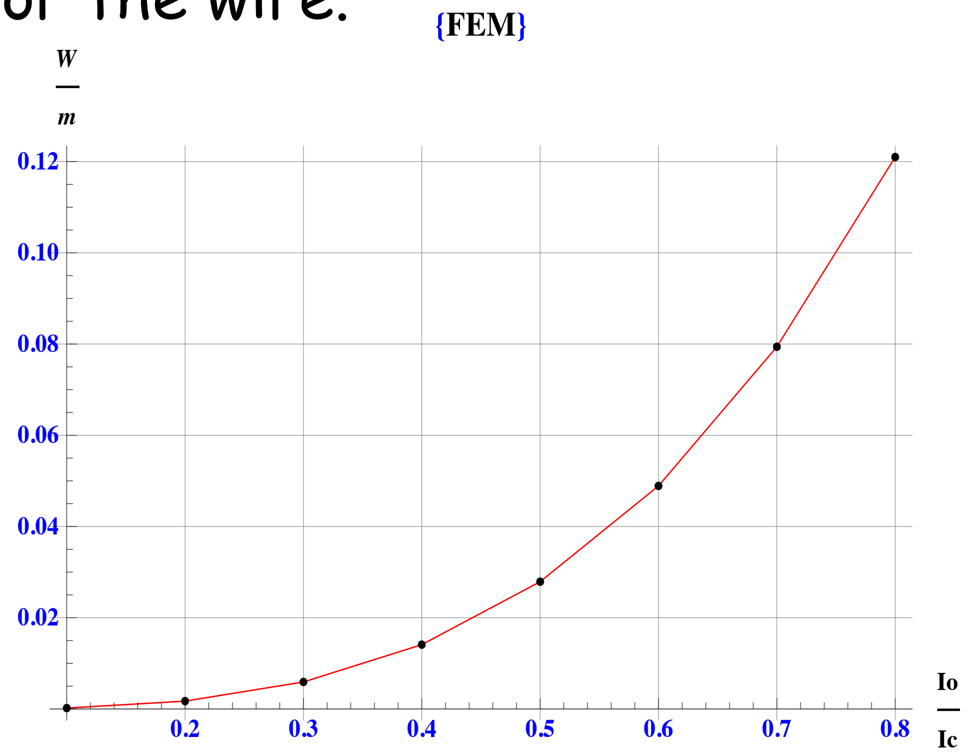
Critical currents:
1.13mm: 200Amps @ 20K, 1T
0.85mm: 135 Amps @ 20K, 1T

50 Hz AC-loss in MgB_2 wire from FEM simulations

- (A) 1.1 mm diameter, 12 strands (B) 1.65 mm diameter, 19 strands
- Critical current at 20 K & 0.5 T: I_c = 380 A
- FEM data are well fitted by the Norris formula with the coherence factor A = 0.48 for the wire.

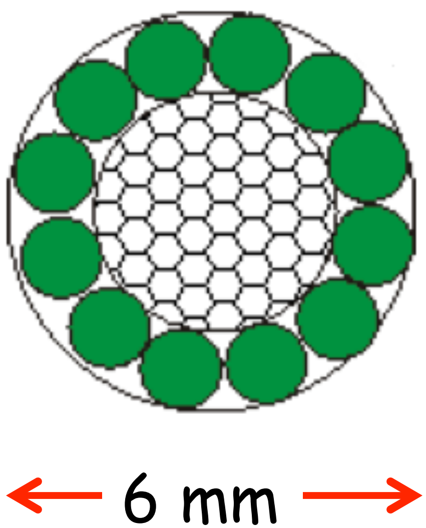
FEM simulations for the upper configuration

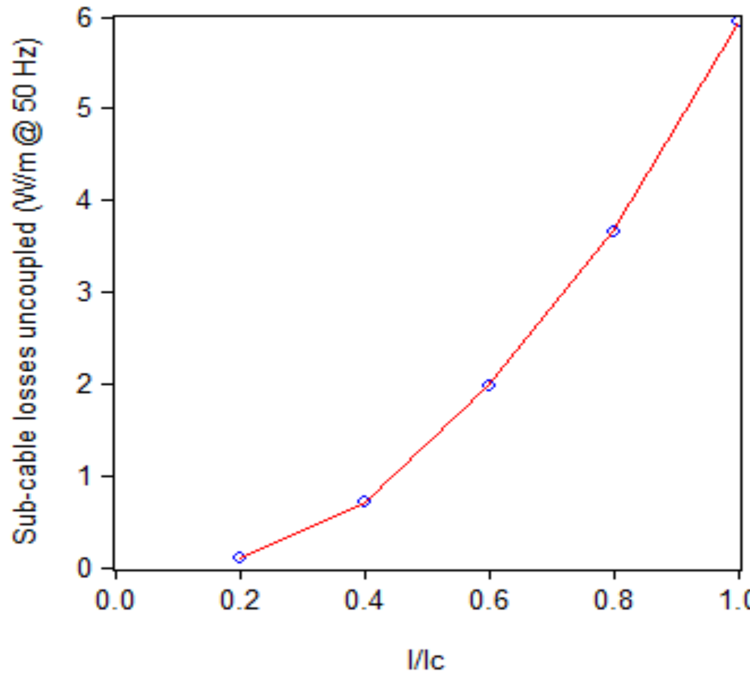




50 Hz AC-loss in 6 mm cable from FEM simulations

- 6 mm diameter, 12 twisted wires
- Critical current at T = 20K and B = 0.8T: I_c = 4560 A
- The AC-losses at 50 Hz are modest due to twist (uncoupling) of the wires. The upper value is only 5.94 W/m at the critical point Io/Ic = 1. For untwisted wires, the present values would be almost by factor 10 larger. *The Norris formula fails to fit the loss in the cable.*

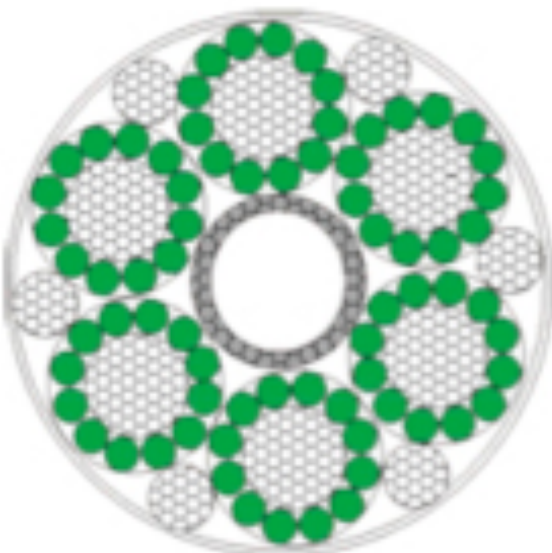




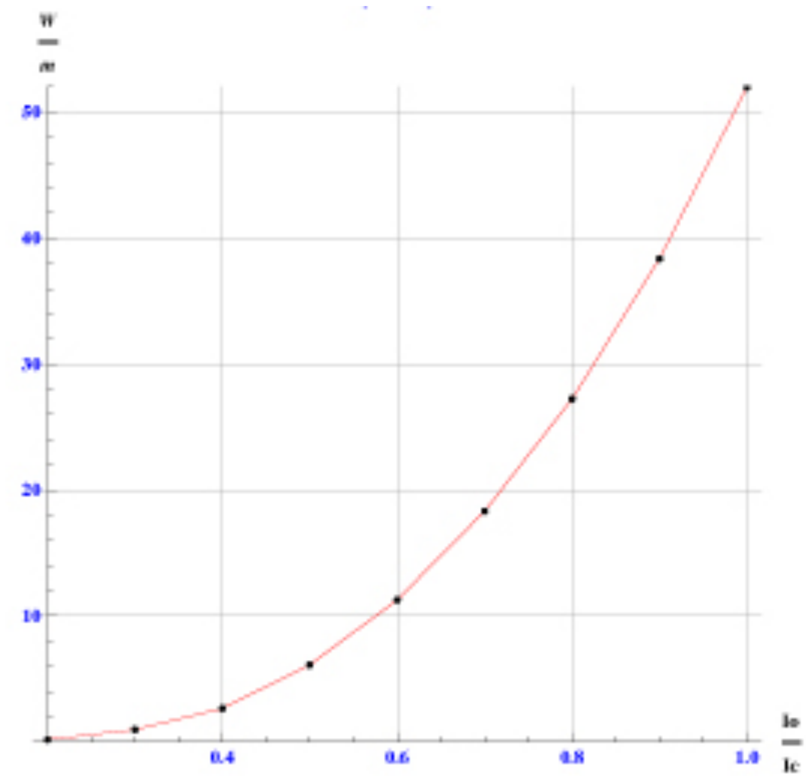
At i/i_C = 0.4 (1800 A) losses are 0.7 W/m P = 0.45 GW with 250 kV rms

50 Hz AC-loss in 1.8 cm cable from FEM simulations

- 18 mm diameter, 6 sub-cables wound around open helical core, twist pitch 0.5 m
- Critical current at 20K and 0.8T: I_c = 27360 A
- The twist (uncoupling) of the sub-cables is taken into account. The ac-loss is 6.1 W/m at Io/Ic = 0.5



← 18 mm →

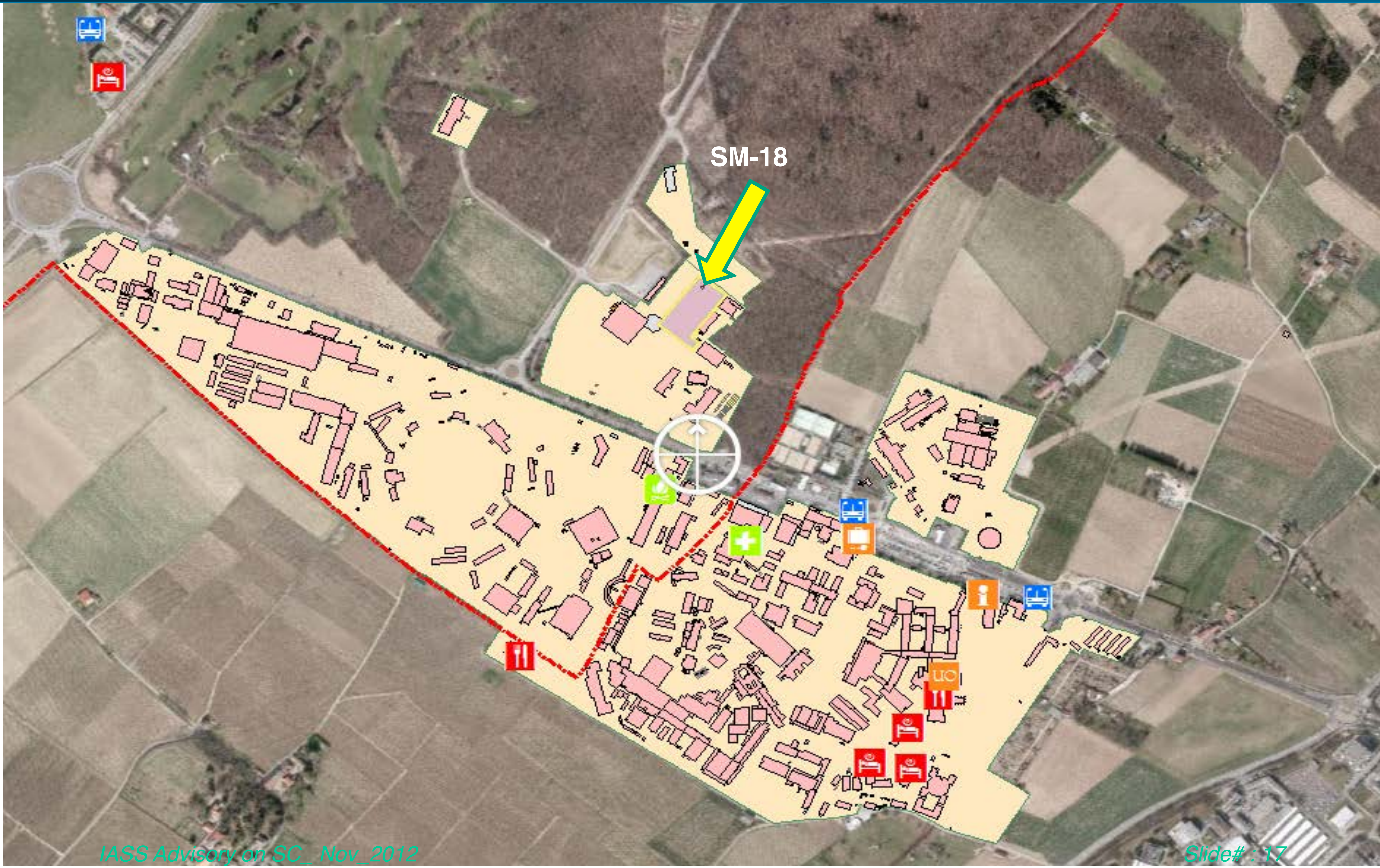


At i/i_C = 0.5 (13680 A) losses are 6.1 W/m
P = 3.5 GW with 250 kV rms

The CERN-IASS testing facility for MgB_2 (Amalia Ballarino)

- Design of a test station enabling the electrical characterization of SC MgB_2 cables operated in helium gas at various temperatures in the range 5 K to 70 K. with the use of existing cryogenic and electrical infrastructure available in the laboratory SM-18
- 20 kA DC power converter; liquid He (6 kW He refrigerator) as well as the space required for integration of long transfer lines. 18 kW for test of LHC magnets) 25 000 LHe Dewar
- First objective: test of cables with a length of up to 20 m, later extended to > 60 m. Vertical configurations.
- Dedicated data acquisition, control and quench protection systems available
- Commissioning of full system in July 2012 – before technical stop in the SM-18 (August and September). Operation as from end of 2012.

Location of SM -18 building at CERN

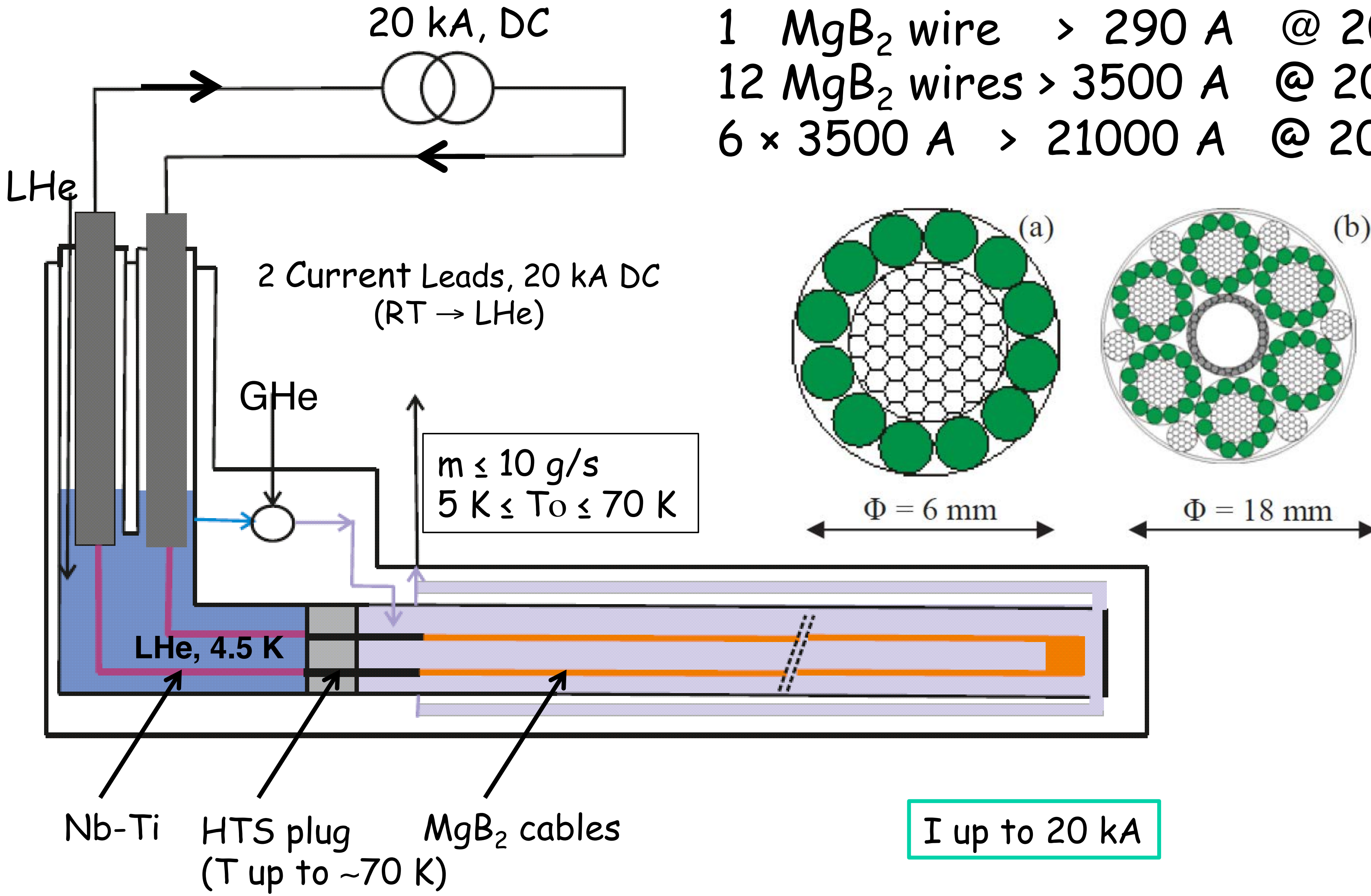


Conceptual design of the 20 m tube with MgB_2 cable

1 MgB_2 wire > 290 A @ 20 K

12 MgB_2 wires > 3500 A @ 20 K

6 × 3500 A > 21000 A @ 20 K



Status of the assembly - September 2012

Conclusions on CERN-IASS programme

- Several test stations for the characterization of wires and cables at 4.2 K are available at CERN and are being used for the characterization of MgB_2 conductor
- A novel test station for the measurement of MgB_2 cables in He gas in a variable temperature range and at DC currents of up to 20 kA has been conceived and constructed.
  - The commissioning has been completed.
  - This test station will enable the measurement of 20 m long MgB_2 cables at any temperature between 5 K and 39 K. The test station will then be extended to 60 m.
  - Different types of MgB_2 20 m long cables will be tested and their performance studied in nominal and transient conditions.

A programme with Industry: Smart Energy Networks in FP7 (presentation by Frédéric Lesur)

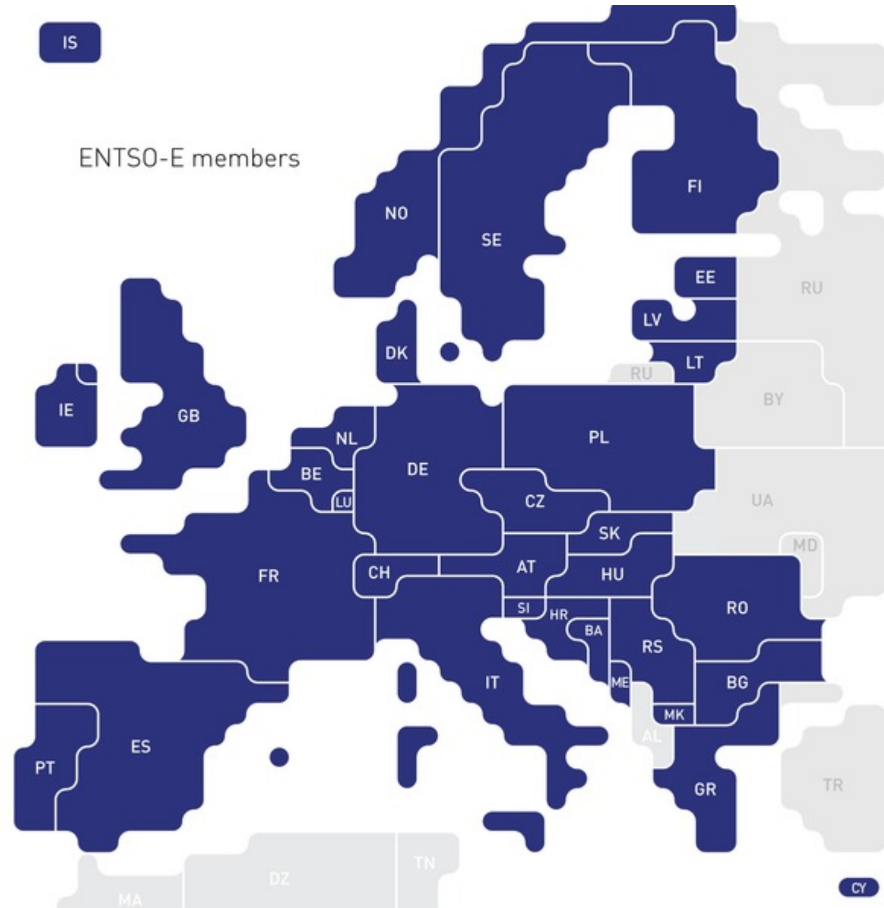
- Evolution of the IASS-CERN programmes with an active industrial involvements.
- Large-scale demonstration within FP7 of innovative transmission system integration and operation solutions for (inter)connecting renewable electricity production.
- Funding schemes and eligibility criteria: Collaborative Project (at least three independent legal entities in different countries of the EU) with a predominant demonstration component.
  - Indicative EU budget: 45 M€.
  - Total budget 90-110 M€
  - Deadline: 24 January 2013.
  - Evaluation: March 2013, main list May 2013.
  - Grant agreements by December 2013.

Transmission System Operators (TSO's)

- The European Commission wishes and encourages Transmission System Operators (TSO's) in the preparation to the call FP7-Energy.2013.7.2.3. TSO's proposes the following topics :
- 2 topics related to HVDC networks :
  - A demonstrator of Interoperability of a DC network with converters from different manufacturers
  - A demonstrator of a multi-terminal DC network
- 2 topics related to innovative solutions to increase the power capacity of links :
  - Increasing capacity of an existing AC overhead line
  - Innovative high power and long distance superconducting link based on MgB_2
- These four topics would be gathered in one common proposal coordinated by REE the Spanish TSO.

European network of transmission system operators for electricity (ENTSO-E)

- Possible partners in the field of power grids:
  - RTE is an active member of ENTSO-E.
  - ENTSO-E is an association of transmission system operators (TSO), operational since July 2009, in order to ensure the coordination of network operation by common tools, and to develop a ten-year network



High-power long-distance cryogenic power line

High power

High current

- Characterization of the superconducting wires, assembled conductors, connections.
- Behaviour during short-circuit (design of the copper former, electrodynamic stress, energy dissipation).
- Ability of being a natural fault current limiter (FCL).

High voltage

- Performance of the cryogenic fluid as a dielectric component (nominal operation and during faults).
- Maximum permissible electrical fields (cable and accessories).
- Progressive system energizing, breakdown management, fault containment.

Very low temperature

- Performance of the super insulation layers, energy efficiency of the system.
- Design of the hydraulic system.
- Safety issues, metal embrittlement.

Long distance

- Analogy with natural gas industry.
- Choice of the installation mode (buried), management of corrosion.

Development of commissioning tests, monitoring and diagnostic methods, maintenance and repair procedures.

Ability to extrapolate a reduced scaled model (prototype) to a large-scaled demonstrator.

- Identification of the required skills (existing within our working group, and missing),
- Identification of required partnerships,
- Deliverables,
- Task leaders,
- Milestones.

Highlight the items complying with a "**predominant demonstration component**".

WP Number	WP Title	Type of activity	Lead contributor	Partners	Comments
WP 1	Project management (administrative and steering activities)	MGT	Nexans		To be discussed with REE
WP 2	Scientific coordination	COORD	IASS	All	
WP 3	Optimization of MgB_2 wires	RTD	Columbus	Nexans, KIT, CERN	
WP 4	Cable system	RTD	Nexans	KIT, CERN , RTE, ESPCI	DC and investigations on AC systems
"WP5"	*"Cooling system "*	*RTD*	*Absolut system ?*	*Nexans*	
WP 6 a	Testing in Gas He	DEM	Nexans	RTE, CERN, KIT	Long term Test at "Les Renardières" desirable for the project
WP 6 b	Testing in H2 (Optionnal)	DEM	KIT	Nexans H2 partners+ *Certification body + Linde*	desirable for the project *To be confirmed*
WP 7 a	Reliability and maintenance of the system	RTD	RTE	Nexans , Absolut system	
WP 7 b	Integration into the Grid	RTD	RTE	Nexans, KIT	
WP 8	Safety of the system in H2	RTD	H2 partner?	Nexans, RTE, KIT, ESPCI	*Certification body & Material ageing in H2 academic partner*
WP 9	Socio economic impact	RTD	Nexans	All	
WP 10	Dissemination and exploitation	OTHER	IASS	All	

- Open questions:
  - A FP7 Industrial Programme will start in 2014 for 4 years
  - Participation from IASS ?: people, topics, resources and so on.

General considerations

- Our initial report on the use of the MgB_2 was dedicated on high power DC line configurations and at the highest powers. The value of 10 GWatt has been exemplified. A necessary distance of several thousand kilometers has been indicated .
- However the actual development of a realistic SC programme must be organised into several successive phases. A first intermediate, practical SC approach with a lower power and at shorter distance is a necessary step.
- The distance for such a a practical application may be substantially shorter, maybe of the order of several kilometers or less. The transmitted power should aim at the order of about a few GW rather than 10 GW.
- The success of such intermediate step appears as a necessary prerequisite for the ultimate goals of the SC/Mg_2 programme.

Main demonstrator

Characteristics	
Structure	Monopole
Power	6,4- to 8 GW
Voltage	320 to 400 kV
Current	20 kA
Length	~ 30 m
Cooling medium	Liq N_2 for the voltage insulation He gas then liquid H2 for MgB_2 conductor

1. Current testing at CERN at 20 kA
2. Full qualification (320 or 400 kV and 5 to 7 kA separately) in Hanover with He gas
3. Current and voltage testing at KIT with liquid hydrogen

Public acceptance (presentation by Heiko Thomas)

Thank you !

"I'm starting to get concerned about global warming."

From an "unthinkable" idea to the future realization of an accomplished industrial programme !

The view of the German Ministry

- At the IASS Strategy Advisory Board Volkmar Dietz from the German Ministry noted that the contributions of the project Advisory Group should be particularily useful for the socio-economic aspects, especially since, according to the BMBF, the MgB2 based approach does not represent the least expensive superconducting technology.
- He also stressed the point that German partners should be more involved, in order to retain some of the benefits also at the national level.