Best Paths

Transmission for sustainability

An MgB_2 superconducting cable for very high DC power transmission

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(on behalf of the Best Paths Demo 5 project team)

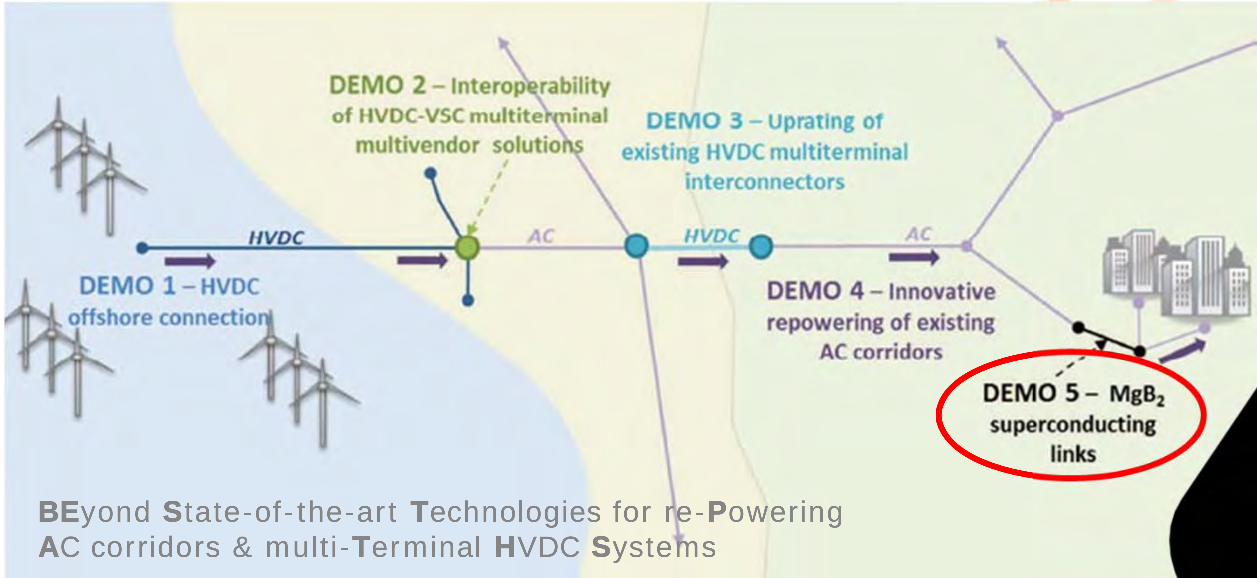
Jicable HVDC'16 WORKSHOP

[Topic 3]

BEST PATHS stands for "BEyond State-of-the-art Technologies for rePowering Ac corridors and multi-Terminal Hvdc Systems". It is co-funded by the European Commission under the Seventh Framework Programme for Research, Technological Development and Demonstration under the grant agreement no. 612748.

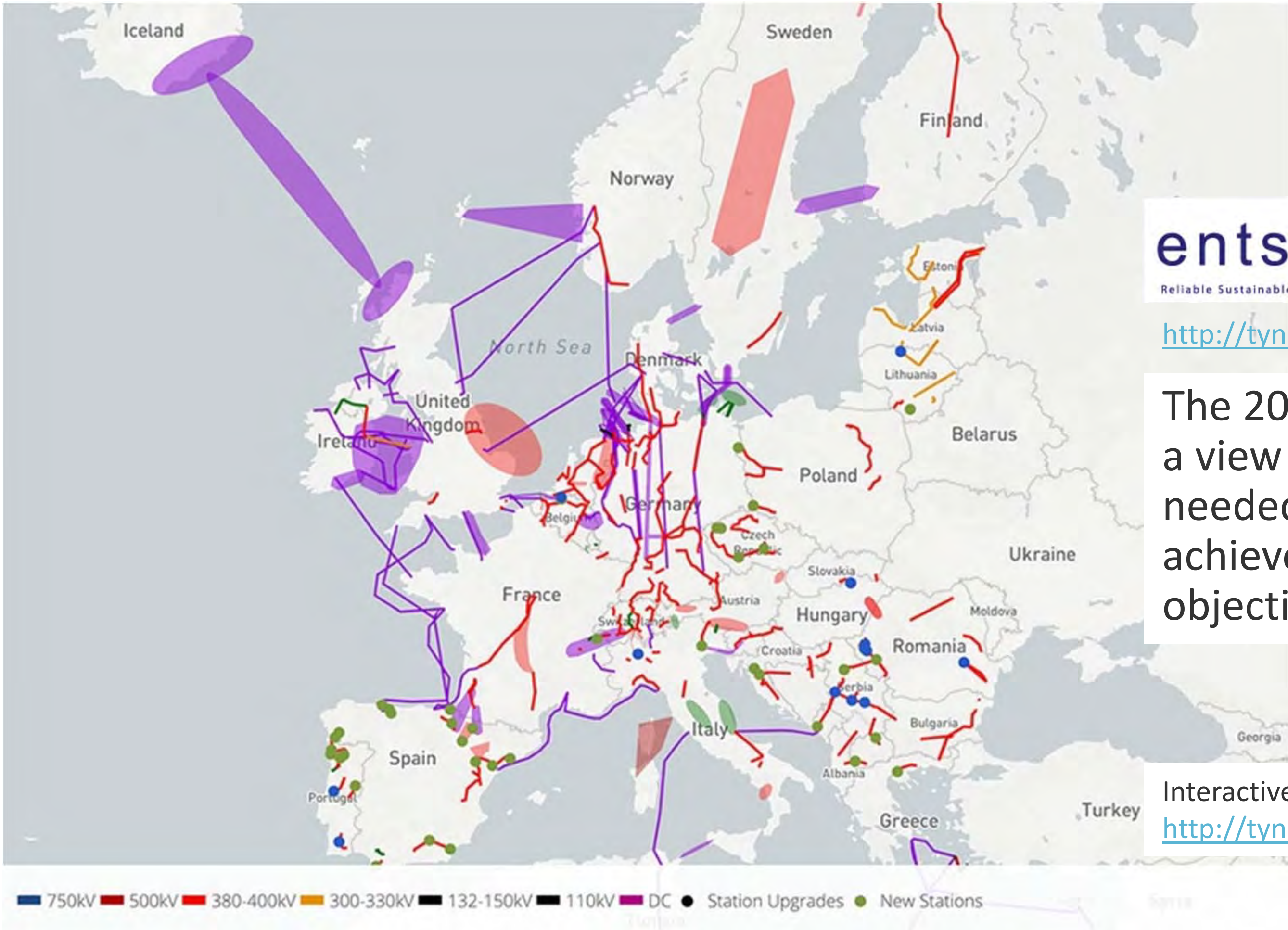
A project to overcome the challenges of integrating renewable energies into Europe's energy mix

Best Paths Project: the largest project ever supported by the European Commission R&D Framework Programs within the field of power grids



October 2014 September 2018	Total budget (EC contribution: 57 %) 62.8 M€ = M$ 70.8 = 460 M¥

TYNDP = Ten-year network development plan (ENTSO-E)



entsoe
Reliable Sustainable Connected
european network of transmission system operators for electricity

http://tyndp.entsoe.eu

The 2016 edition offers a view on what grid is needed where to achieve Europe's climate objectives by 2030

Interactive map:
http://tyndp.entsoe.eu/reference/#map

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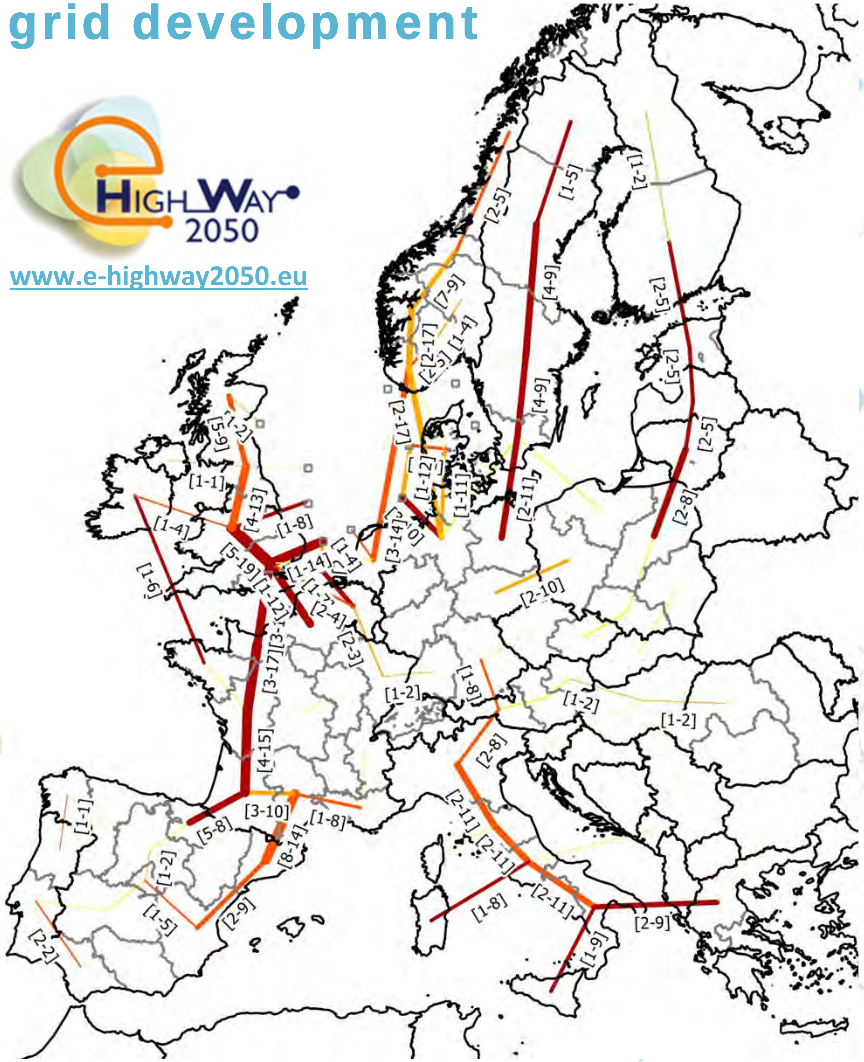
Future prospects of transmission grid development

European **eHighWay2050** Project brings very useful input data

- New methodology to support grid planning
- Focusing on 2020 to 2050
- To ensure the reliable delivery of renewable electricity and pan-European market integration
- Five extreme energy mix scenarios considered

www.e-highway2050.eu



Whatever the scenario, 5 to 20 GW corridors are identified

- Major North-South corridors are necessary
- Connections of peninsulas and islands to continental Europe are critical

How to transmit more than 4 GW over long distances?

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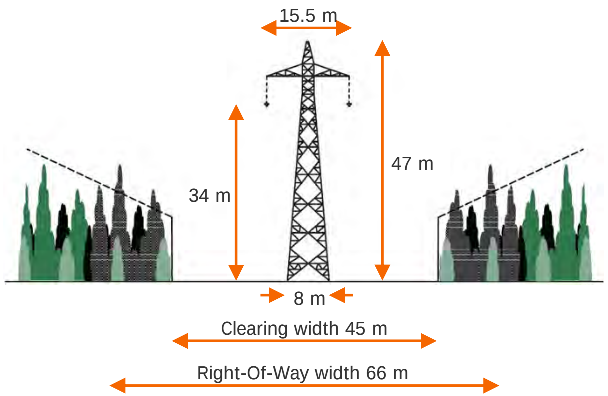
How to transmit bulk power 3-5 GW? (examples of corridors)

Nelson River DC line (Canada)
1600+1800 MVA (+2000 under construction)



Geneva, Palexpo Link 2001,
470 m, 220 kV / 2 x 760 MW

Frankfurt Airport,
Kelsterbach Link 2012,
900 m, 400 kV / 2 x 2255 MW

Raesfeld (380 kV AC, Germany)
2x 1800 MW

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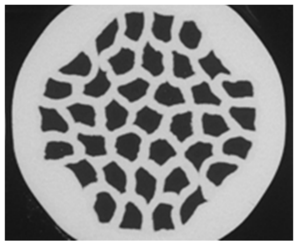
Main objectives of the superconducting demonstrator

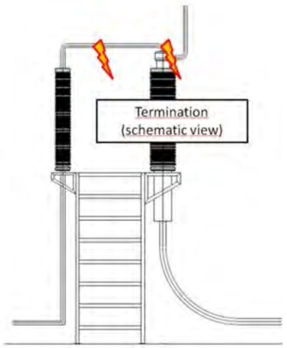
10 partners to demonstrate the following objectives

- Demonstrate full-scale **3 GW** class HVDC superconducting cable system operating at 320 kV and 10 kA
- Validate the novel **MgB_2** superconductor for high-power electricity transfer
- Provide guidance on technical aspects, economic viability, and environmental impact of this innovative technology

Process development to manufacture a large quantity of high performance MgB_2 wires at low cost

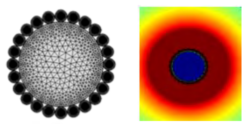


Cable and termination development + manufacturing processes



Validation of cable operations with laboratory experiments performed in He gas at variable temperature

Operating demonstration of a full scale cable system transferring up to 3.2 GW



System integration pathways for HDVC applications

Investigation in the availability of the cable system

Preparation of the possible use of H_2 liquid for long length power links

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10 project partners

Nexans
- Demo coordination
- Optimisation of MgB_2 wires and conductors
- Cable system
- Cryogenic machines
- Testing in He gas
- Integration into the grid

CERN
- Optimisation of MgB_2 wires and conductors
- Cable system
- Testing in He gas

Columbus Superconductors
- Manufacturing and optimisation of wires

IASS Potsdam
- Scientific coordination
- Dissemination

KIT Karlsruhe Institute of Technology
- Cable system
- Liquid hydrogen management

Technische Universität Dresden
- Cooling systems

ESPCI ParisTech
- Cable system
- Dielectric behaviour

Universidad Politécnica de Madrid
- Integration to the grid
- Reliability and maintenance

RSE Ricerca Sistema Energetico
- Cable system

RTE
- Integration into the grid
- Socio-economical impact

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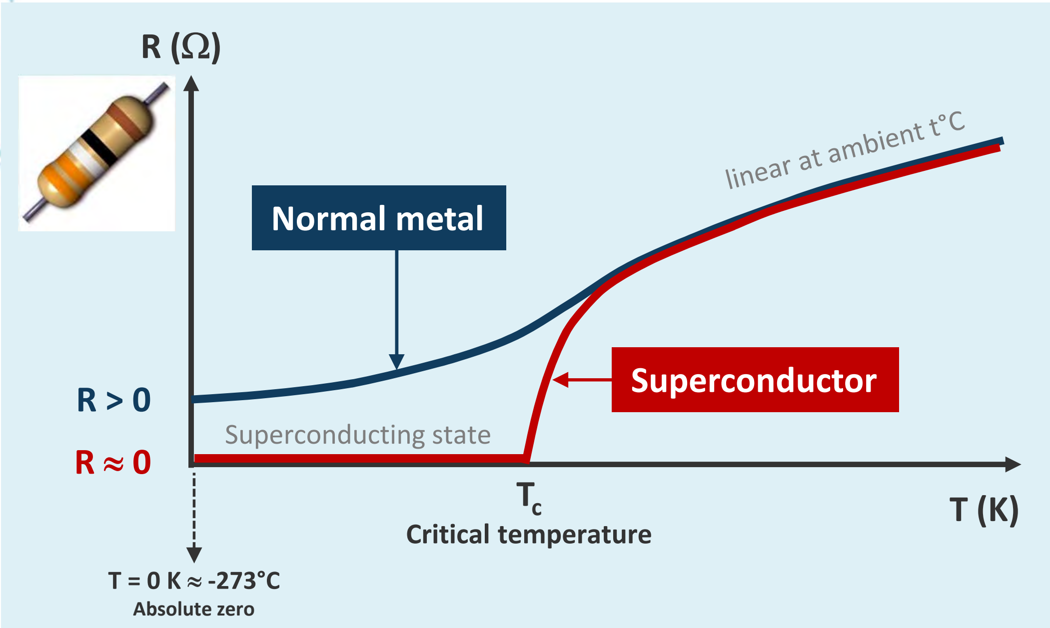
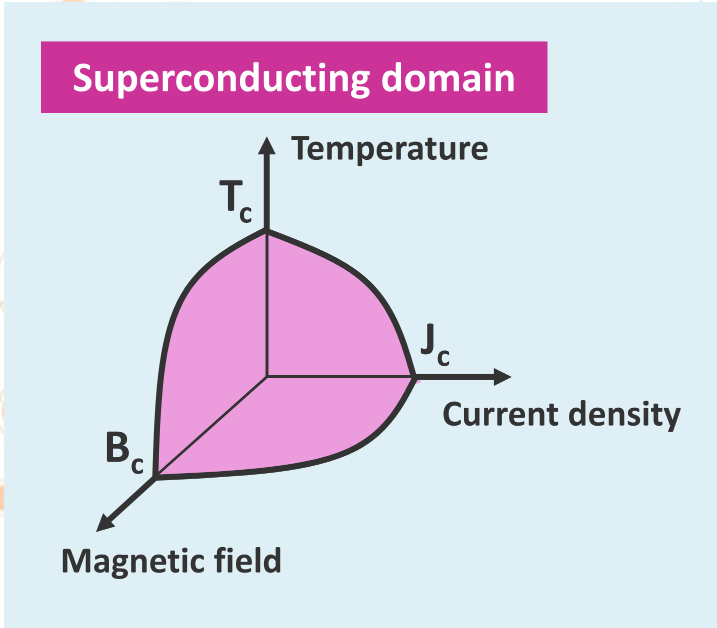
What is superconductivity?

Superconductors = almost perfect conductors of electricity:
no electrical resistance!





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Requirement of cooling at very low temperatures

T = 0°C ≈ 273 K
(water becomes ice)

Ambient temperature

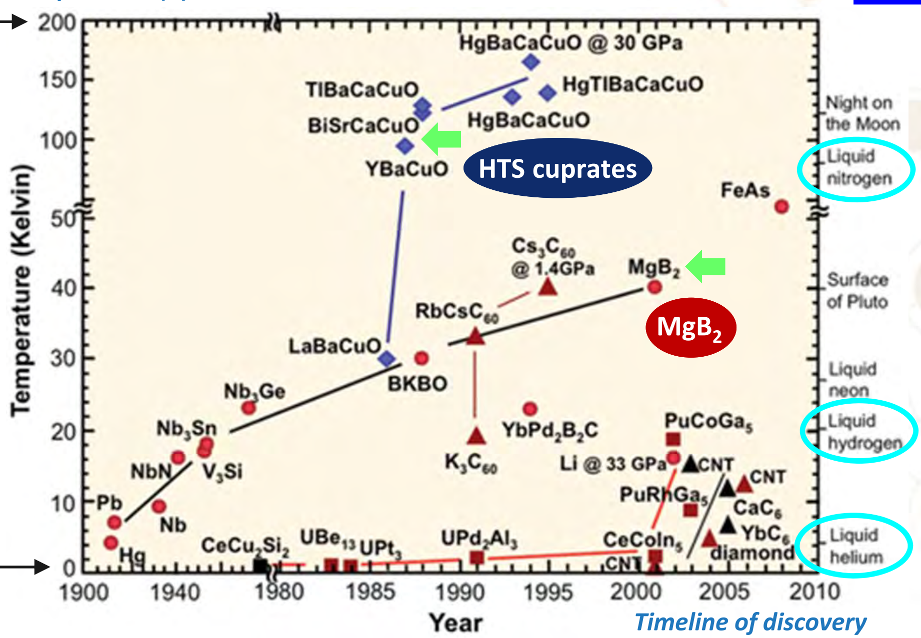
T = 200 K ≈ -73°C

Industrial cooling

Extreme cold

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

Superconducting materials



Cryogenic fluids

Liquid nitrogen

Liquid hydrogen

Liquid helium

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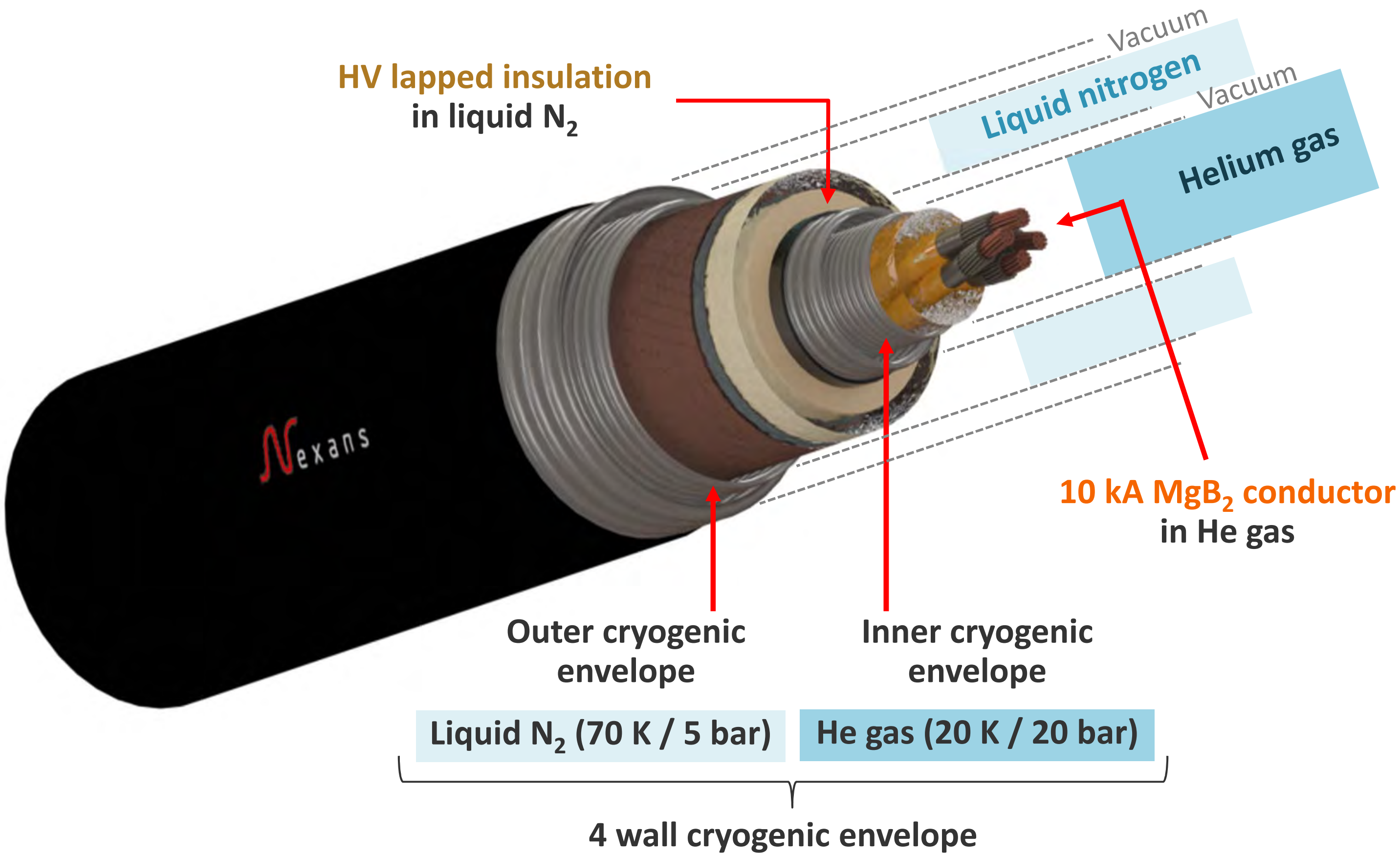
Conceptual design

Two fluids to guarantee reliable operation



Demonstrator characteristics
Monopole
3.2 GW
320 kV
10 kA
20 - 30 m

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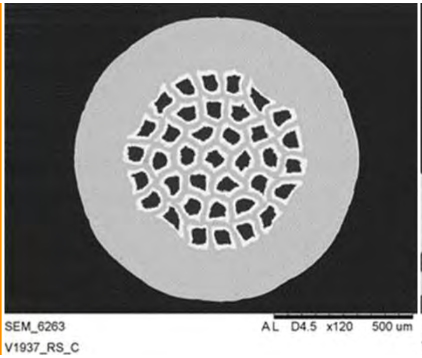
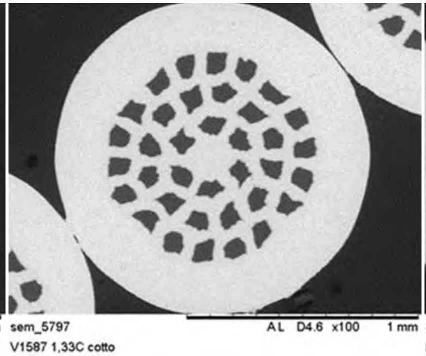
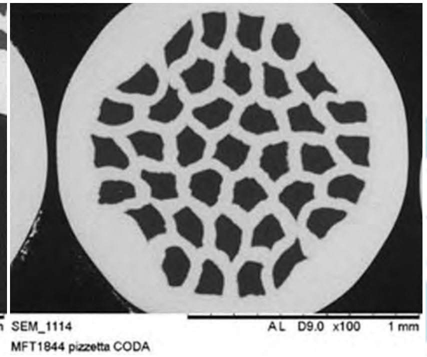
MgB_2 wires: designs optimised for kilometre-long pieces

New design proposed for specific requirements in Best Paths







MgB_2 wires	
Diameter (mm)	1.0 to 1.5 mm
Materials	Monel (copper and nickel alloy), nickel

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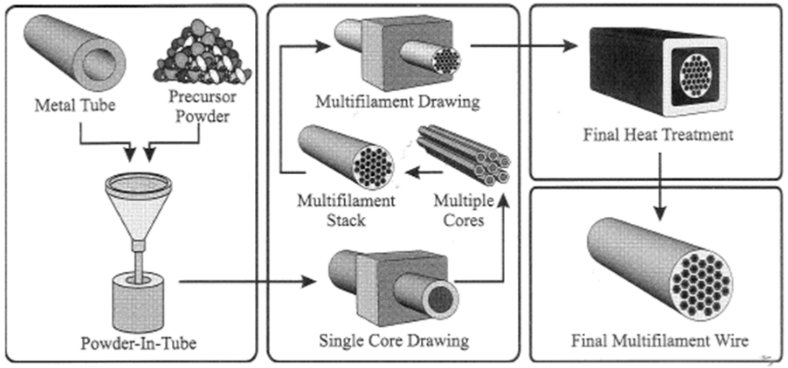
MgB_2 wires manufacturing (Columbus SpA process)

Industrial machines to roll, draw, swag and anneal

Clean synthesis of powders



High power straight drawing machine

20 meter long in-line furnace

Multistep drawing machine

Multistep rolling machine

4 meter furnace for annealing HT

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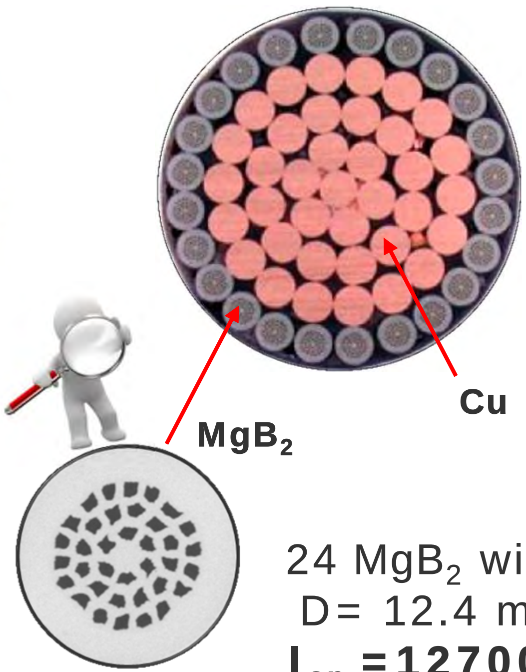
MgB_2 cable conductor



24 MgB_2 wires
D= 12.4 mm
I_{op} =12700 A

Possible MgB_2 wires cable arrangements

18 to 36 MgB_2 wires + Cu core

- Concentric geometry
  external diameter of 9 to 15 mm
- High critical current
  13 to 22 kA
- Easy to connect

Electrical characterization of cable prototypes at CERN

- measurement of the critical current of 10-meter long cables tested in liquid (at 4.3 K) and gaseous helium (between 15 and 30 K)
- comparison with specifically developed FEM models including the nonlinear contributions of the magnetic matrix of the MgB_2 wires

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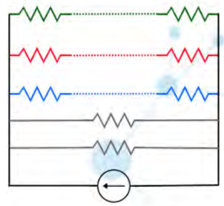
MgB_2 cable conductor: modelling of thermal losses



Power inversion from 100 MW/s up to 10000 MW/s

- Ramp-up I(t) dependence according to TSO scenarios

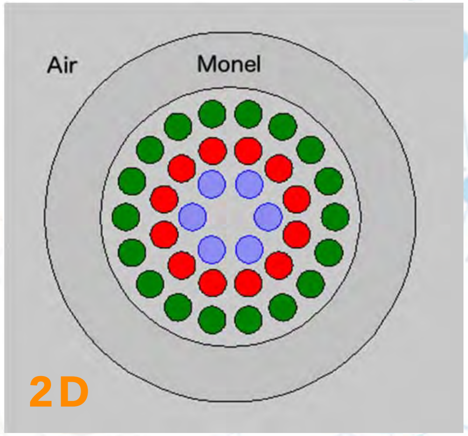
Fault current: 35 kA during 100 ms

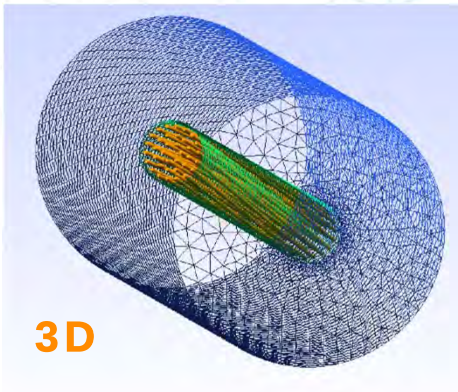
- FEM model: estimation of the temperature after a fault current due to the shared current through the resistive parts of the cable conductor
- Estimation of the recovery time after fault

Ripple losses due to current source into the MgB_2 wires

- Assessment of the most appropriate numerical modeling 2D (fast) vs. 3D (long)

→ 3D modeling also evaluates coupling losses





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MgB_2 cable conductor: planned measurements

Investigations of the quench behaviour

- dedicated measurement setup
- measurement of minimum quench energy, normal-zone propagation velocity, quench load, and hot-spot temperature
- development of FEM numerical models of the quench behaviour of the cable

Interstrand contact resistance

- development of experimental setup
- development of an electrical network model to extract the values of the contact resistance from the measured data

Joint resistance

- development of FEM models for the expected joint resistance between high-current cables
- measurements of joint resistances between wires and cables in liquid and gaseous helium

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Cable system: Developing the termination components

Hybrid current leads for the current injection

- Prototype of current lead manufactured and ready to be tested in critical current at 70-77 K
- FEM modeling by KIT: total heat load expected per current lead in He gas at 20 K is lower than 3 W

Cryogenic HV insulated line for the helium gas injection

- Fiber reinforced polymer solution for the inner tube into a tubular grounded cryostat
- Principle: connect insulated tube with metallic flanges at extremities to guaranty the tightness

G 11 tubes

KF flange

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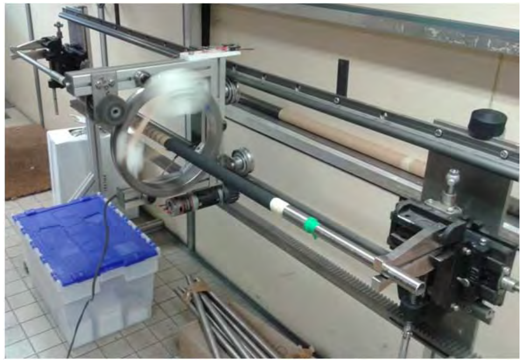
Cable system: HV cable insulation

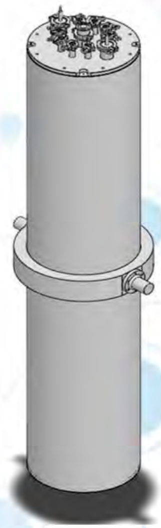
Cable insulation = Lapped tapes impregnated with liquid N_2

- **Versatile lapping line** designed for the preparation of short samples (70 cm)
  - Tape materials (paper, PP, PPLP, etc.)
  - Dimensions (thickness, width,...)
  - Pitches and gaps between tapes



- **First samples** manufactured with Kraft paper and shipped to ESPCI for tests

- **Design of sample holder** for testing the cable insulator close to operating conditions
  - Up to 60 kV (possible upgrade to 120 kV)
  - Up to 5 bars pressure in LN_2
  - With a slow fluid flow
  - Using the pressure-wave-propagation method
  - Temperature regulation by exchanger above the sample



- **Design of a measurement system** for determining the space charge distribution in the insulating part of the sample
  - Using the pressure-wave-propagation method

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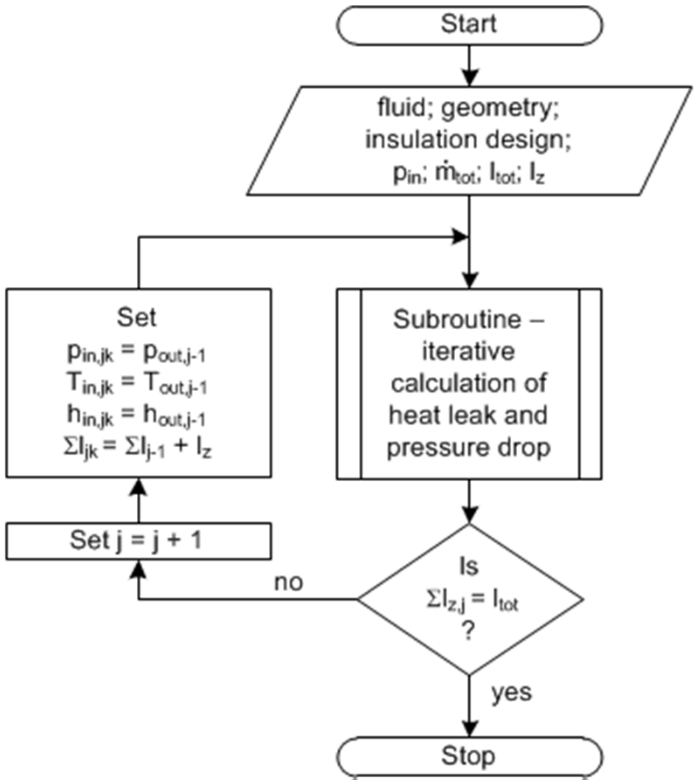
Cryostat and cooling systems



Cryogenic system design

- Review of correlations for the evaluation of the pressure drop and heat losses of the superconducting cable
- Program flow chart of the thermohydraulic model
- Publication of the requirements and specifications of the cooling system parts for the demo

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Availability of the system

Conceptual design of the cooling system for a multi-kilometer superconducting cable

- Modular system keeping a temperature well where the cable lies
- Radial inward heat flow is removed by a cooler at the end of each cryostat module, which is filled by a cryogenic fluid below 25 K
- Inner tube surrounded by a vacuum chamber that could be thermally insulated with a flow of liquid N_2 outside at 70-77 K

3 fluids have been studied for filling the inner tube

- He gas, liquid H_2 and liquid Ne

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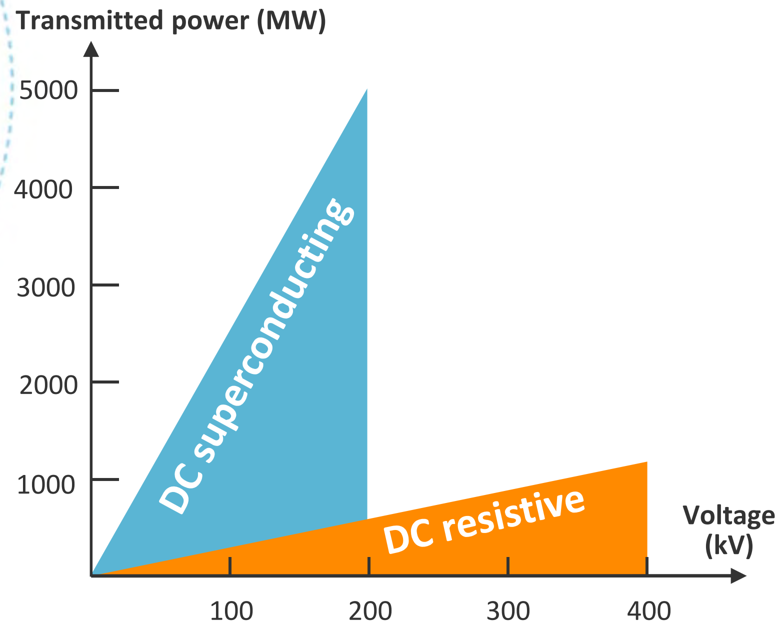
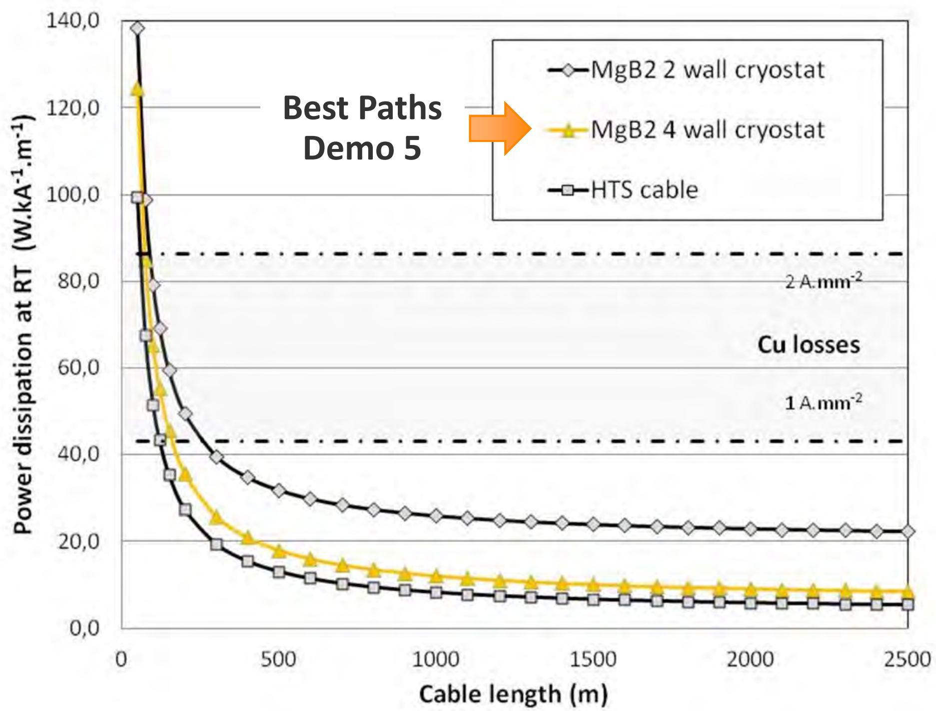
Best Paths
Transmission for sustainability

Expected results and impact

Increased power at a reduced voltage level



Reduced power transmission losses



Eco-friendly Innovations in Electricity Transmission and Distribution Networks, Woodhead Publishing Series in Energy: Number 72; 2015 Edited by Jean-Luc Bessede P158

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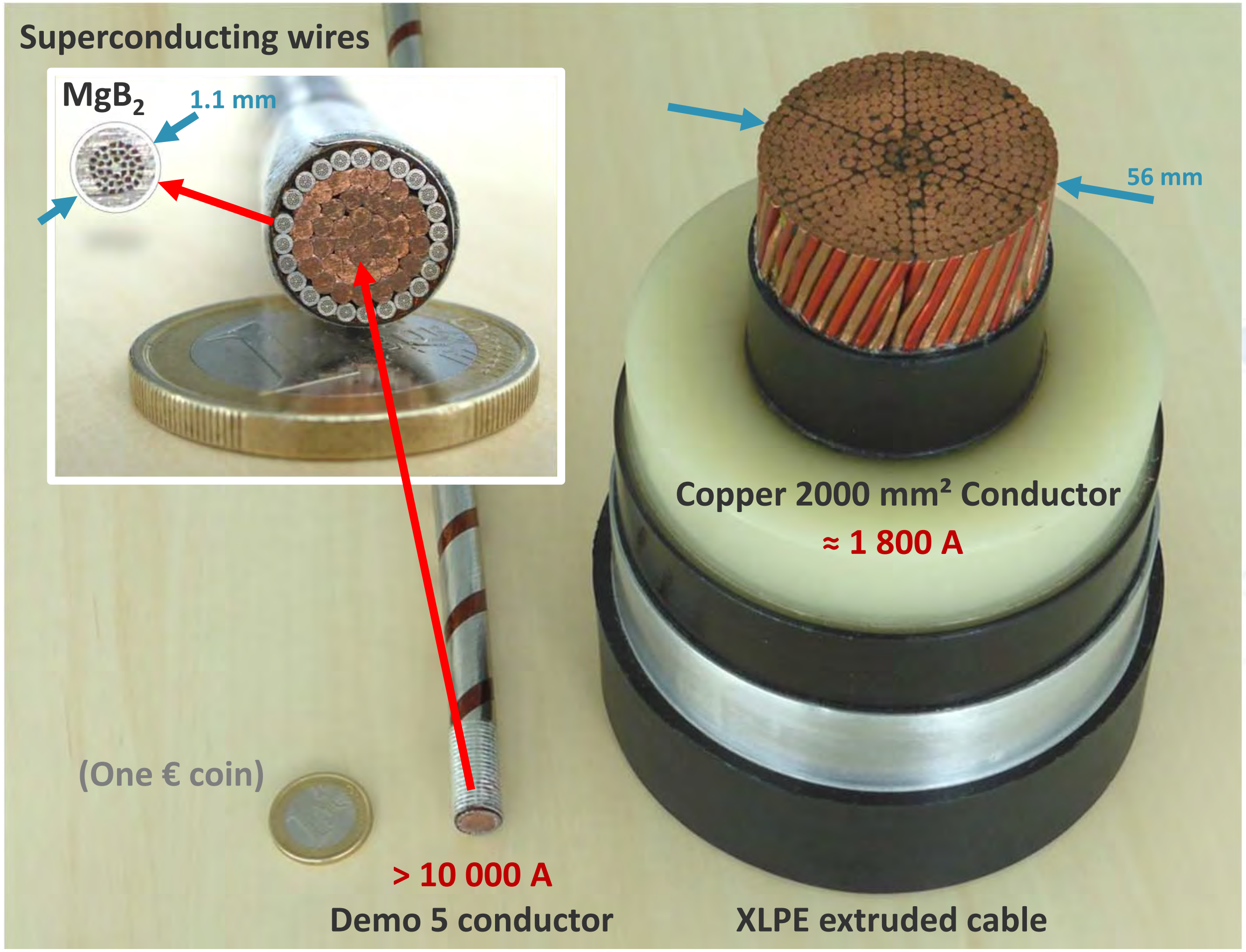
Consequent reduction of raw materials



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Reduced space for cable installation and substations

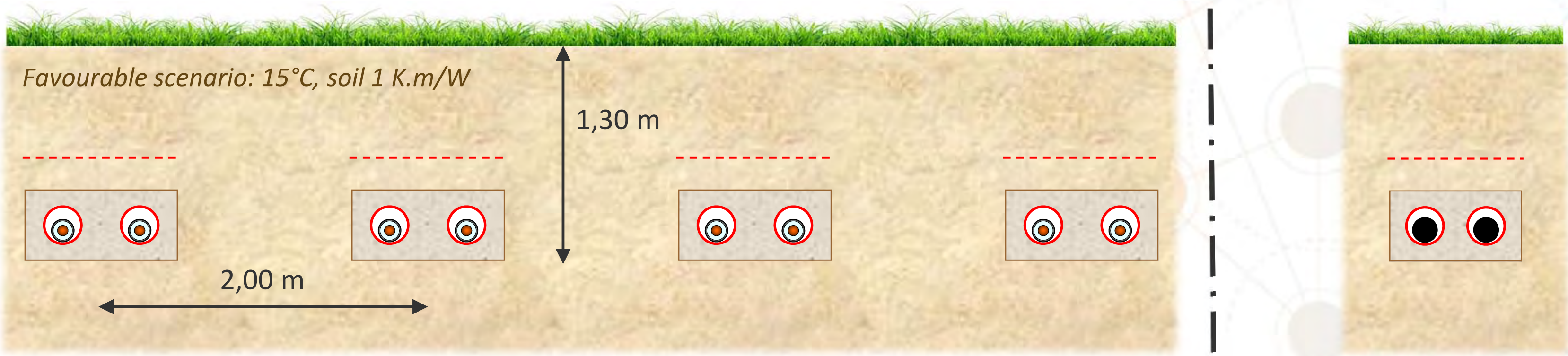
Significant reduction of right-of-way corridors and of excavation work

No thermal dependence to the environment

<u>*Example*</u>*:* 6.4 GW DC power link with XLPE cables

Foot print = 7 m

Foot print = 0.8 m



Resistive cables (8 x 400 kV - 2 kA)

Our Best Paths Demo 5
(2 x 320 kV - 10 kA)

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Conclusions

The world energy transition requires new power grid developments

- The simulations performed within the eHighway2050 Project showed a high need for transmission grid expansion in 2050 to fulfil the European decarbonisation target (corridors of 5 to 20 GW)
- The building of these corridors meets strong opposition and may take decades
- Alternative underground solutions have to be deployed at a reasonable cost

Resistive solutions (overhead lines, XLPE cables, GIL) involve large rights of way or extensive civil engineering, and are ambient temperature dependant

An MgB_2-based HVDC superconducting cable system promises very attractive performance and will be developed and tested by ten partners of Best Paths Project until September 2018

- Operating a full-scale 3 GW cable system (at 320 kV and 10 kA)
- Validating the novel MgB_2 superconductor for bulk electrical power transmission
- Providing guidance on technical aspects, economic viability, and environmental impact of the innovative technology

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