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STATUS OF THE MgB_2-BASED HIGH POWER DC CABLE DEMONSTRATOR WITHIN BEST PATHS

CHRISTIAN ERIC BRUZEK, AMALIA BALLARINO, GUILLAUME ESCAMEZ, SEBASTIANO GIANNELLI, GIOVANNI GRASSO, FRANCESCO GRILLI, CHRISTOPH HABERSTROH, STÉPHANE HOLÉ, STEFFEN KOEPPEL, FRÉDÉRIC LESUR, ADELA MARIAN, AND MATTEO TROPEANO

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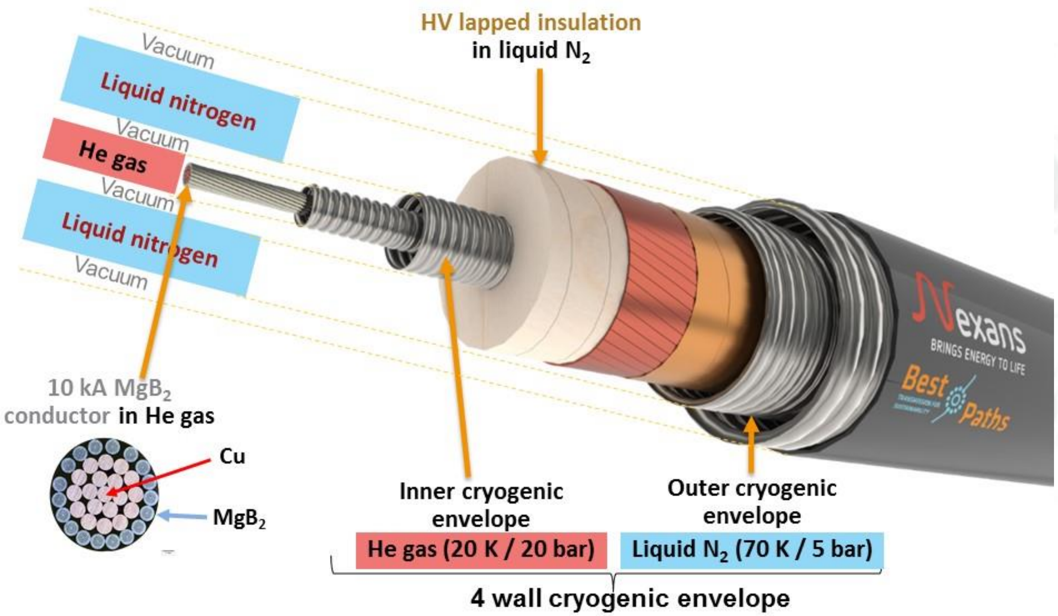
Objectives of our demonstration

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



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Demonstrator technical specification and testing strategy

Characteristics	
Structure	Monopole
Power	3,2 GW
Voltage	320 kV
Current	10 kA
Length	~ 20 m
Cooling media	Liq N_2 for the electrical insulation He gas for MgB_2 conductor
Losses of the demonstrator	< 50 W He gas (~20 K)
Fault current	35 kA during 100 ms
AC Ripples on 10 kA DC current	< 1% amplitude 50 Hz
Change of power flow direction	100 MW/s up to 10 GW/s

- Test of operating conditions on the demonstrator
- But use only modeling to check the cable behavior during faults and polarity changes

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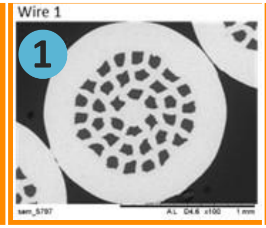
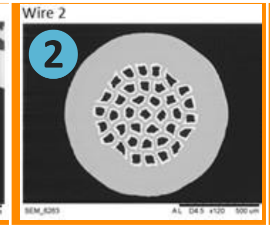
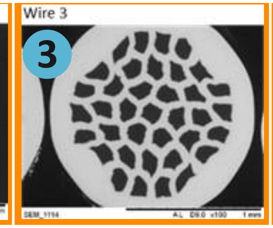
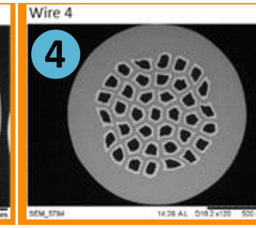
RESULTS

Completed R&D work on the MgB_2 round wires

MgB_2 wires				
Diameter (mm)	1,3	1,0	1,5	1,5
Materials	Monel, Ni	Monel, Ni, Nb	Monel, Ni	Monel, Ni, Nb
MgB_2 volume fraction	17 %	12 %	30 %	12 %
I_c (A) @ 20 K & 1 T	500	300	> 650	> 650
I_c (A) @ 4,2 K & 3 T	280	400	> 700	600
r_c (mm)	125	100	200	150

- Wire diameter homogeneity achieved along the entire batch length of about **2 km**
- Confirmation of the wire process capability to stay within the **specification limits**

For more details please see presentation 4MO2-06

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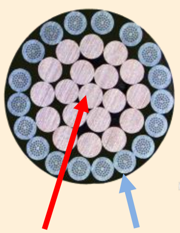
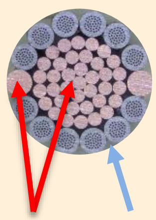
RESULTS

MgB_2 cable conductor designs with a fault tolerant configuration

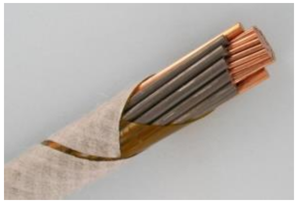
Two cable conductors considered

Base design with wire #1	**Upgraded design with the new wire #4**
18 MgB_2 wires	12 MgB_2 + 2 Cu wires
I_c = 14000 A	I_c = 13700 A
I_{op}/I_c = 0,72	I_{op}/I_c = 0,73
D= 9,6 mm	D= 8,6 mm





✔ Both cables manufactured by Nexans on industrial cabling machines



Performances

✔ *For cable conductor #1*:
- No degradation on extracted wires measured by Columbus Spa
- Validation by electrical characterization prototypes at CERN on 2 meter long prototype cable tested in liquid He (at 4,3 K)

For cable#2: Tests are ongoing

Modeling: transient phenomena

1- Power inversion from 100 MW/s up to 10 GW/s

⚠ Limited 5 GW/s for cable conductor #1

✔ Possible at 10 GW/s for cable conductor #2

2- Fault current: 35 kA during 100 ms

✔ Both design validated

3- Converter ripple losses

✔ Negligible for both cable conductors (< 0,02 W/m)

For more details please see Posters 3LP7-20 & 3LP7-27

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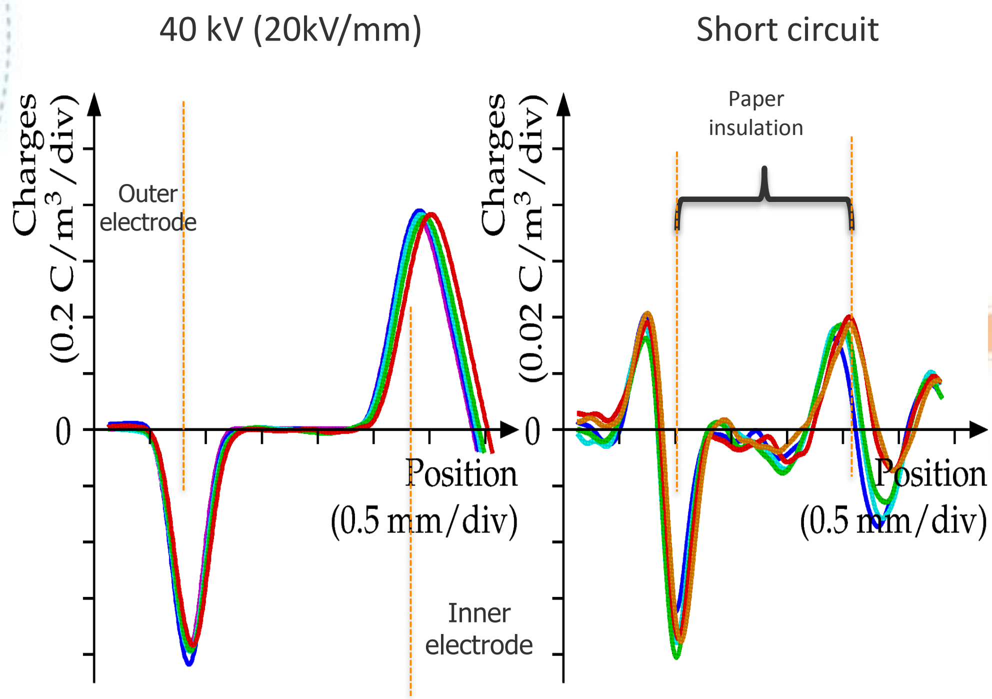
Cable system: HV cable insulation

- 20 tests are applying 40 kV and 60 kV across a 2 mm thick Kraft paper and PPLP impregnated with Liq N_2 at 1 bar and 5 bar have been carried out



- No trapped charge carrier is found in the insulation
- Limited trapped charges due to the carbon black paper electrodes are found at the interfaces
- **HV insulation made using paper impregnated with Liq N_2 looks like a good candidate for HVDC superconducting cable**

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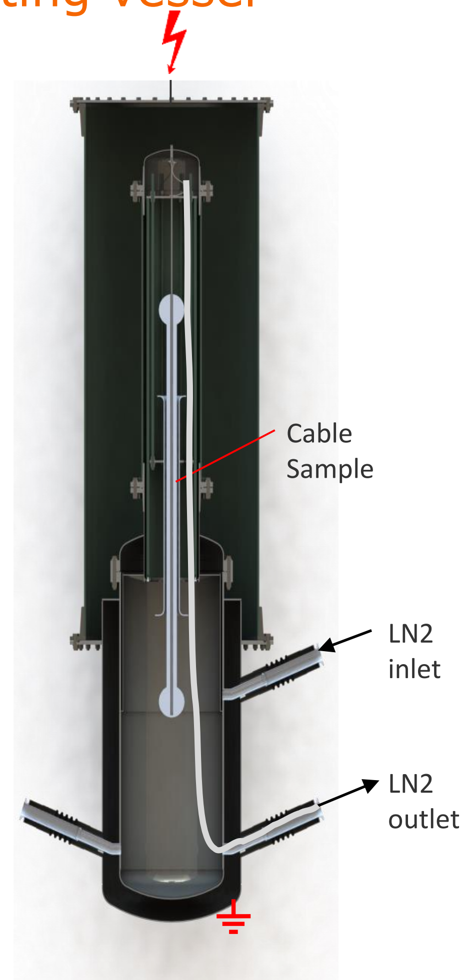
RESULTS

Cable system: Full scale HV cable

Testing vessel



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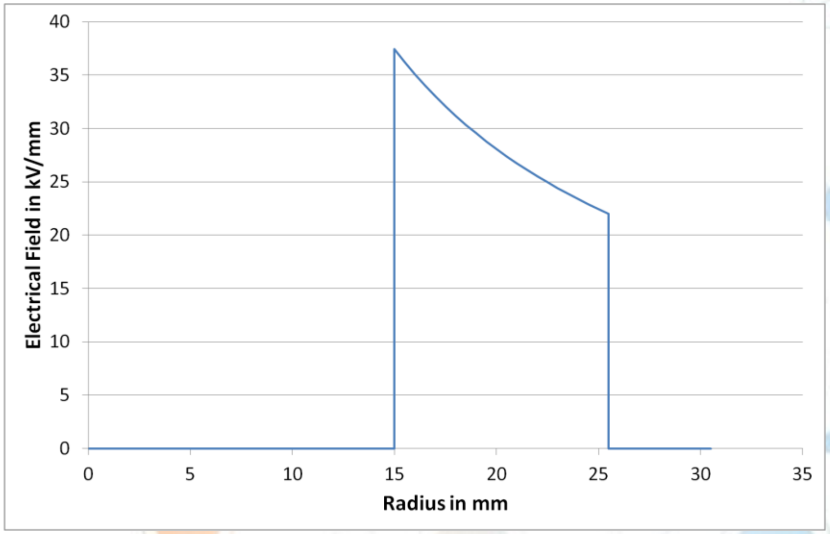
Cable system: Full scale HV cable

Measurements of performances

- Alternating tests AC/DC
- Increase of the test voltages in steps
- Impulse Voltage Test at the End

DC Test Voltage: 298 kV



	Maximum test voltage*	Maximum electrical field
AC	140 kV	17,59 kV/mm
DC	298 kV **	37,44 kV/mm
Impulse voltage	325 kV	40,83 kV/mm

* without breakdown
** based on160 kV nominal voltage level

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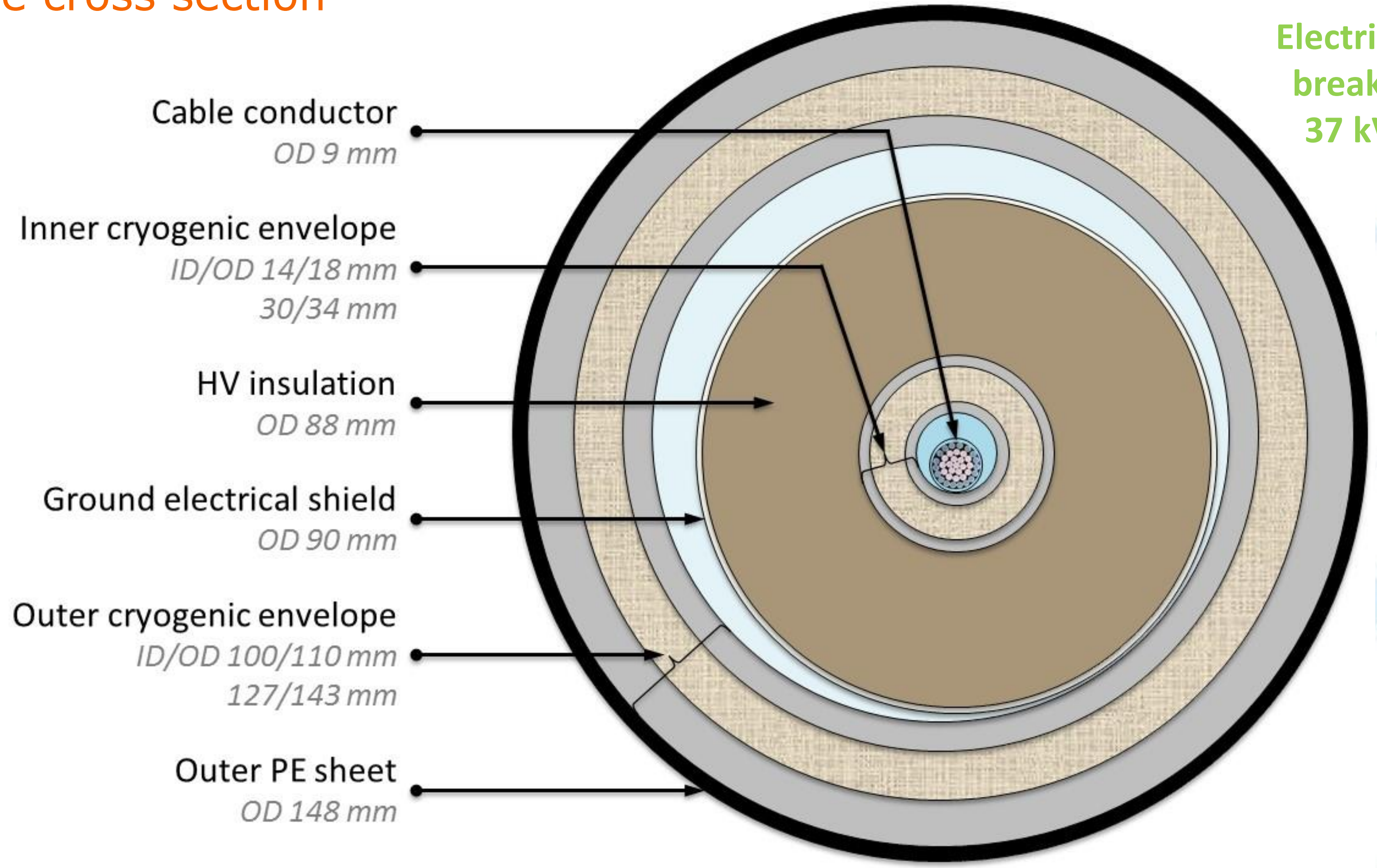
Cable system: Demonstrator design

Cable cross section

For 320 kV DC class cable testing up to **592 kV DC**

Electrical field breakdown: 37 kV/mm



* The two diameters indicate the corrugation depth

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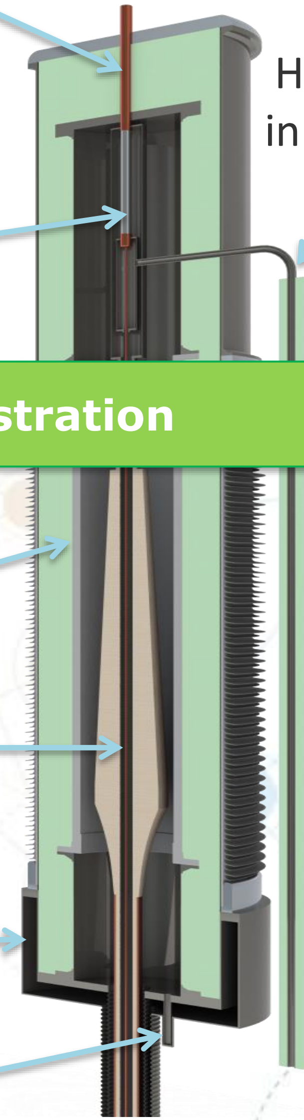
Cable system: Demonstrator design

HVDC termination concept design

≈ 8 m height

2,5 x 2,5 m footprint

Manufacturing has started for the demonstration



Electrical connection to grid

Helium gas inlet / outlet

Hybrid current lead

Inner cryogenic insulator

Elect field management component

Termination cryostat

Liquid nitrogen inlet/outlet

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RESULTS

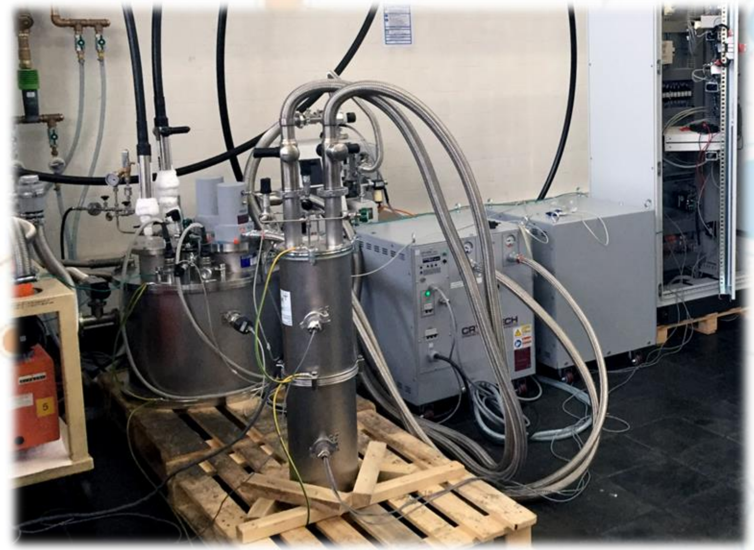
Cable system: Cooling system for the demonstration

Pressurized subcooled Liq N2

Available on Nexans Test HV platform

Cooling system for Gas He 15 to 25 K

<u>Specification</u>: 110 W @ 20 K (20 bar) net cooling power with 1 m³/h He flow rate



✔ Commissioning of the 20 K cooling machine is done

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Demonstrator phase on test platform

So far, no technical blocking point is identified for the demonstration on test platform ✅

The project will enter in its demonstration phase that will be carried out until summer 2018

Based on these concepts, work on grid integration and social and economical profitability is now started….

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Grid integration / Social & economic profitability

eHighWay2050 results

www.e-highway2050.eu

Very long cable system

several 100 km

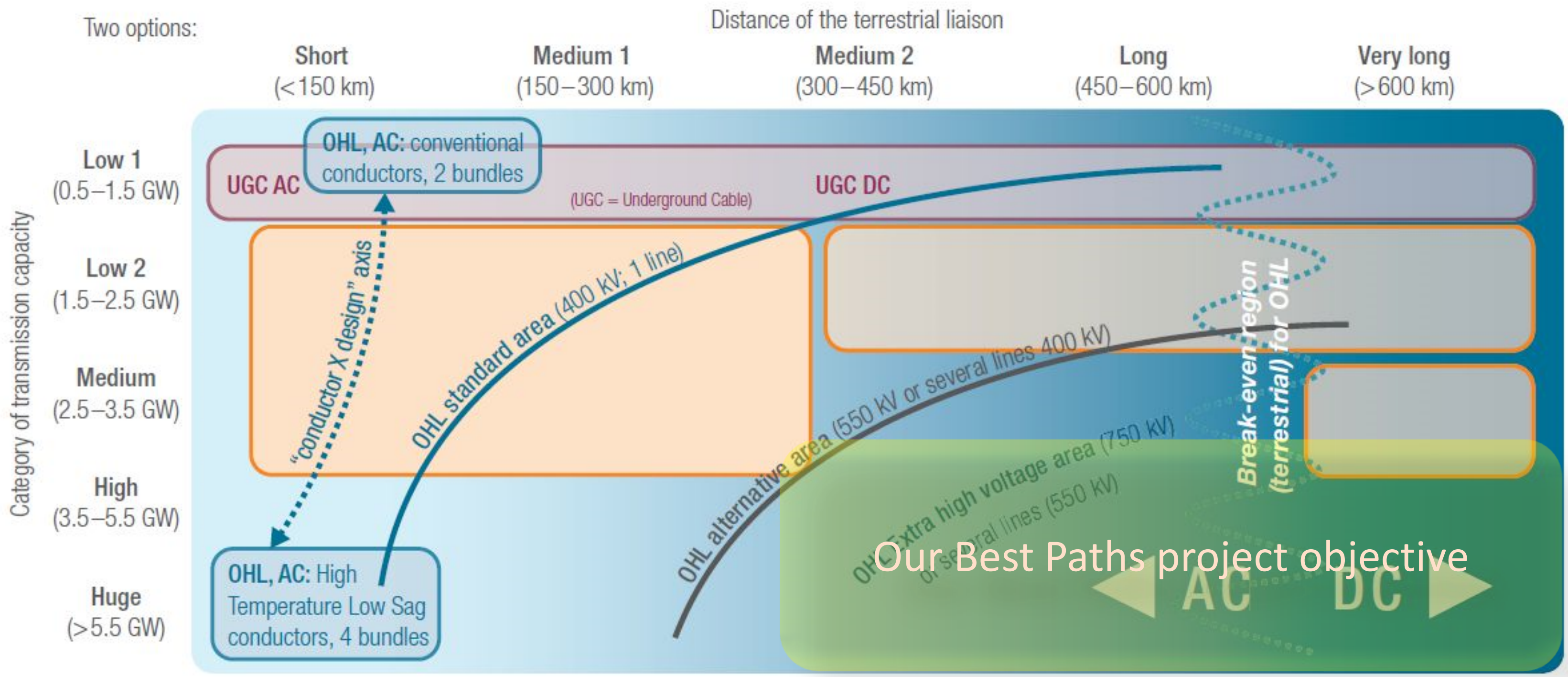

Figure 19: RD&D gap analysis: terrestrial needs (orange cells) compared to available technology options (OHL options: various grades of blue, from the more conventional to the less conventional; terrestrial cables options: in purple color)

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What are the critical parameters for TSO to manage long-length systems?

1. Intrinsic features and design

- Management of a non-resistive component inserted into the transmission grid
- No dependence on scarce resources (e.g. no rare earths, limited volume of **gaseous He**)
- Simplicity of design and execution for the joints (electrical and cryogenic continuity), in order to replicate elementary sections of cable
- Distance between pumping and cooling stations **ideally fitting with existing power substations (in average every 50 km)**
- Ability to face ascending elevation (e.g. **liquid N_2**)

2. Installation

- Delivery of long lengths of cable on drums
- Ability to use existing techniques for civil works and installation

3. Reliability

- Robustness of the system, especially the joints (wire continuity, absence of insulation stress)
- Maintainability, availability and reliability (no outage longer than 2 minutes/year)

4. Public acceptance

- Installation of the underground system along a reasonable and efficient cable route

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Details presented at IWC-HTS (Karlsruhe)

Long length cable concept

First results of the cryostat modeling

Two Cooling Fluids (CF) considered:

- Gas He and Liq H_2

+ Integration of a Liq N_2 thermal shield

[K]	T_{in} CF	15	$T_{in,LN2}$	65
[K]	T_{out} CF	25	$T_{out,LN2}$	80
[MPa]	P_{in} CF	2	$p_{in,LN2}$	2
[MPa]	P_{out} LH2/GHe	0,35/0,5	$p_{out,LN2}$	0,2

Based on analytical approach:

1- Optimized friction factor f [-] = 0,04 (adapted corrugation)

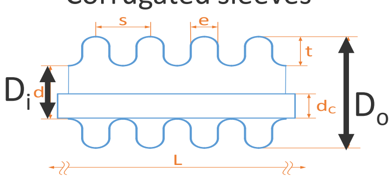
2-Flat installation - no ascending elevation

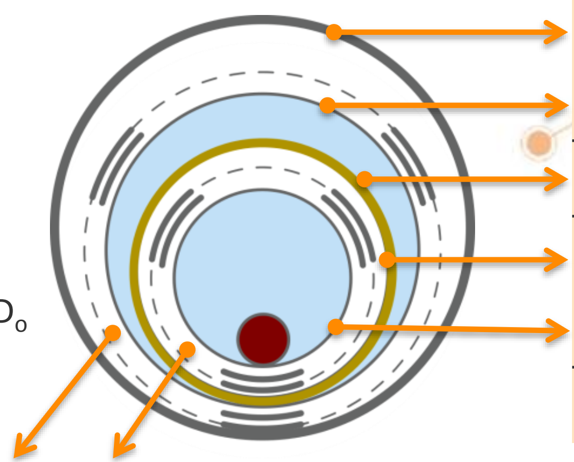
3- Viscosity of Gas He is higher than Liq H_2

4- Density and Cp of Gas He is lower than Liq H_2

Options		G He *Demo based design*	G He Long length	Liq H2 Long length
$D_{i\&o,LN2,}$ O	[mm]	129/143	272/300	272/300
$D_{i\&o,LN2}$ I	[mm]	98/110	228/251	228/251
D_{HVI}	[mm]	90	154	136
$D_{i\&o,CF,}$ O	[mm]	33/37	108/114	91/96
$D_{i\&o,CF,}$ I	[mm]	21/23	93/99	76/81
L_{tot}	[km]	7	62	74

Corrugated sleeves





Vacuum chambers

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Conclusions

1. MgB_2 wire has been specially adapted to the project specifications (reduced losses, higher critical current density)
2. Two possible cable conductors have been manufactured and their characterization is ongoing
3. Accessories *(terminations and cooling systems)* have been designed, specified and partially commissioned
4. So far, no technical blocking point was identified, the project is now ready for the demonstration phase on testing platform
5. First design of cable system has been proposed for long links
6. Based on latest results and envisioned solutions, an analysis of grid integration and socio-economic profitability is now started
7. It will be based on envisioned or already built HVDC links in the network

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Nexans

ESPCI ParisTech

TECHNISCHE UNIVERSITÄT DRESDEN

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POLITÉCNICA "Engineering the future"

We all thank you for your attention!

Any questions?

CERN

KIT Karlsruhe Institute of Technology

Columbus Superconductors

RSE Ricerca Sistema Energetico

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