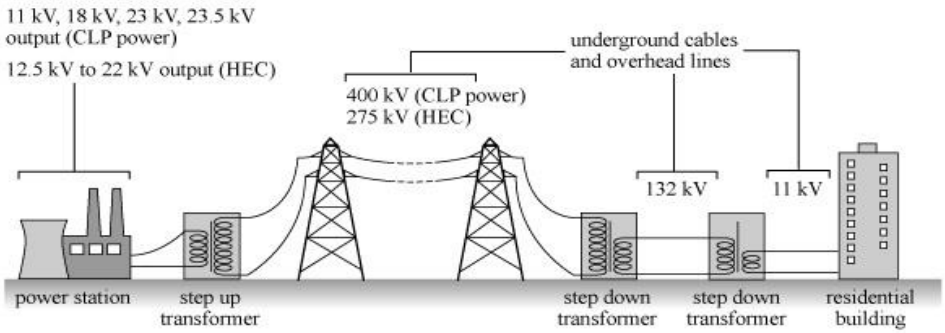
Recent Progress in Developing Superconducting Power Lines

Alexander Chervyakov
Institute for Advanced Sustainability Studies e.V.
Potsdam, Germany
Web: www.iass-potsdam.de

Today's electricity transport

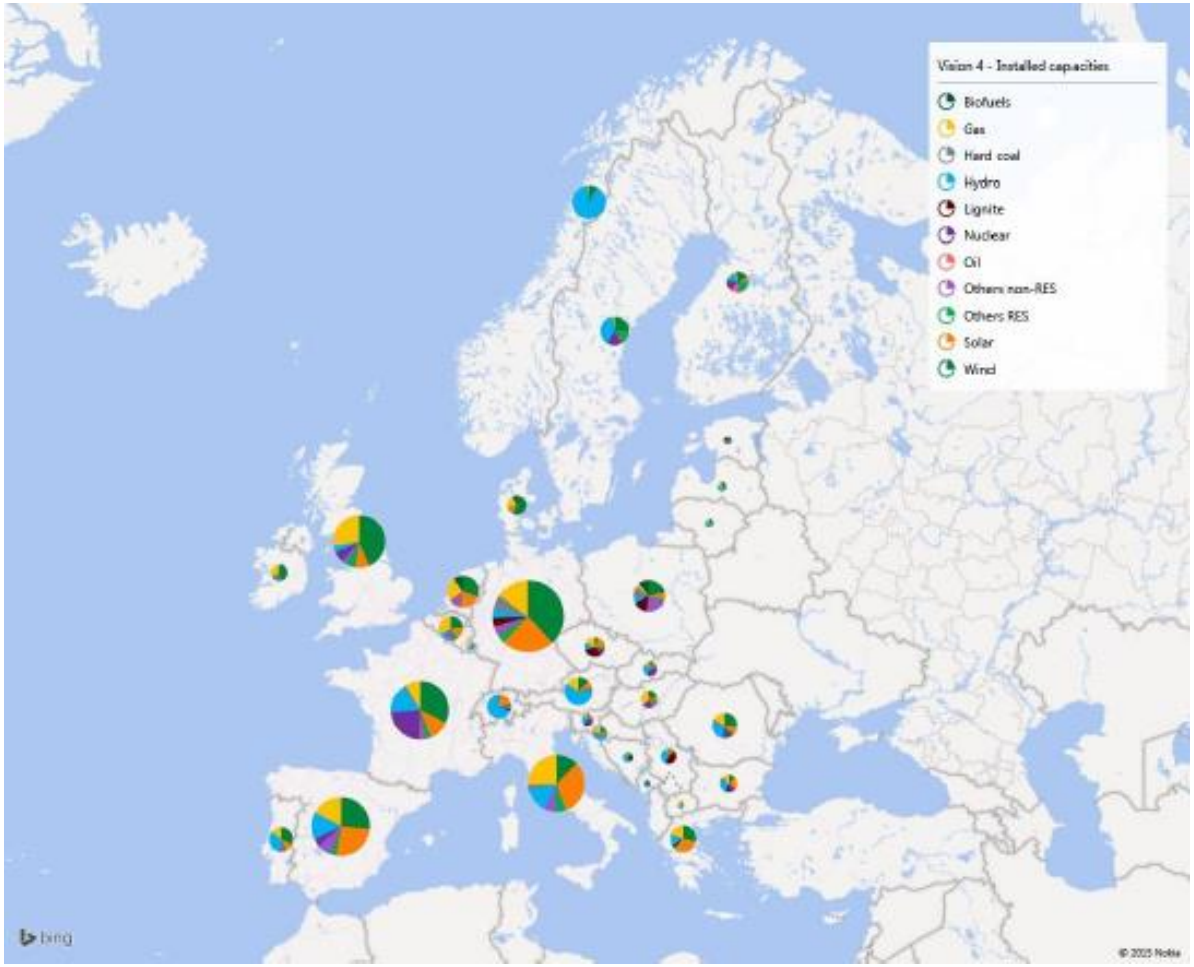
- Plants are set up to generate the electricity near the places where it is needed



- Contrary, natural gas and oil are transported over the distances of several thousand km periodically spaced by compressor stations

- In order to unlock RES potential much longer routes of electricity are required (Europe and Germany as a reference)

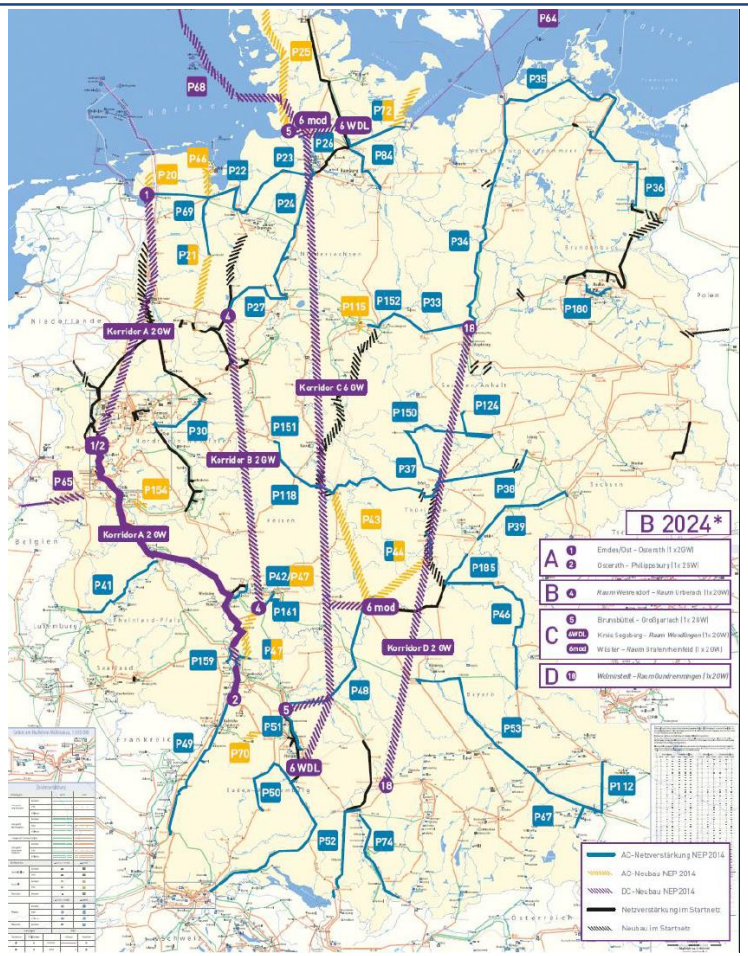
EU grid development



- 50 000 km of new lines (21 000 km HVDC)
- 265 GW of total power
- Up to 60% RES by 2030

Source: TYNDP 2016

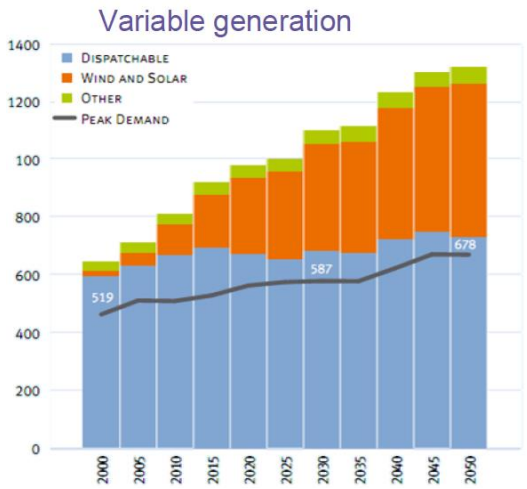
Grid development Germany

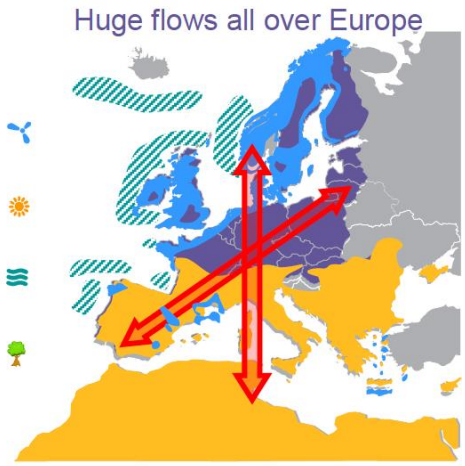


- 4 HVDC corridors
- 12 GW
- 3 410 km

Source: Netzentwicklungsplan 2014

Unlocking RES potential





- Long distances
- Variable generation
- Integrity

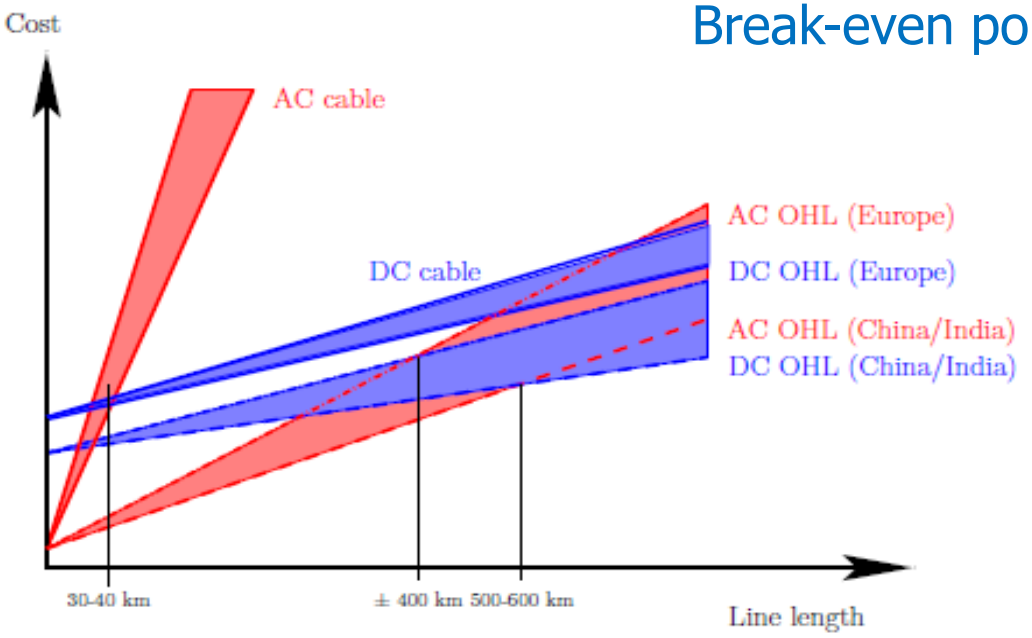
RES and conventional HV power transmission systems

Efficiency $P_{loss} = R \cdot I^2$ high voltage

multiple circuits

- AC: widely used, easy voltage transformations
- DC: more efficient, expensive converters

Break-even points



Source: Van Hertem&Ghandhari

HV (AC/DC) overhead lines

- Low cost, high efficiency
- Easy interconnection
- Good reliability
- Easy and quick to repair
- Lower transmission losses (DC)
- High cost of converter stations (DC)
- Multi-terminal operation (VSC)

- Large visual impact (right of way, land use)
- Large environmental impact (EMF)
- Strong dependence on weather conditions

500 kV AC ~ 300 m
$\pm$ 800 kV DC ~ 130 m

Viable solution for very long distance bulk power transmission
Low public acceptance
No construction of new OHLs (France, Germany)

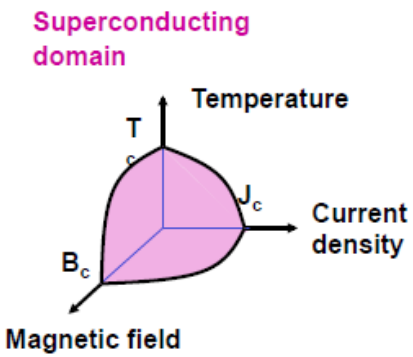
HV (AC/DC) power cables

- Less visual impact
- Reduced right of way
- Less EMF
- High cost
- Capacitive charging (AC)
- Space charge (DC)
- High converter cost (DC)
- Low capacity (DC VSC)
- Heat emission

500 kV HVAC cable ~ 40 km
HVDC VSC cable ~ 320 kV/200-400 MW

Application in densely populated urban or business areas

Superconducting alternative



The technology that capable of changing general principles of electricity transmission:

- high currents at low voltages (current rating up to 5 kA AC and much above of 20 kA DC)
- no needs for step up/down transformers
- moderate HV insulation

Common advantages:

- zero resistive losses, higher efficiency, long distances
- high current carrying capacity: (>150 x copper) -> remarkable compactness in structure
- low dielectric losses (CD design)
- environmental friendly: no EMF radiation, no soil heating

refrigeration and associated losses

Superconducting materials

LTS - Low Temperature Superconductors (Nb3Sn, NbTi):

- Low cost raw materials and simple manufactory process (1 $/kA m)
- But complex cryogenics at 4.2 K (-269 °C) with expensive LHe

HTS – High Temperature Superconductors (1G Bi 2223, 2G YBCO, ceramic based):

- Very expensive raw materials and complex manufactory process (100 $/kA m)
- But simple cryogenics at 70 K (-203 °C) with LN2

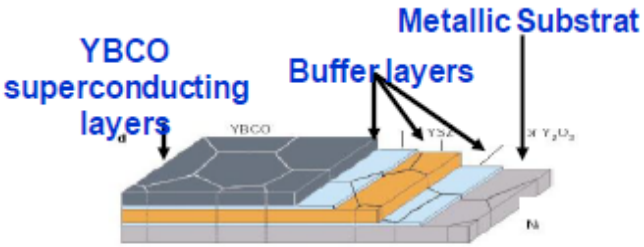
SC Material	Main Coolant	T[K]	Thermo-d factor	Wire cost	Cryogenic complexity	Cable complexity
LTS	Liquid He	1.9-4.2	400	low (5-10 kA m)	high	low
HTS	Liquid N2	60-75	9	high (50-150 kA m)	low	high
MgB2	LH2 or gasHe+LN2	15-20	40	low (1-5 kA m)	low	low

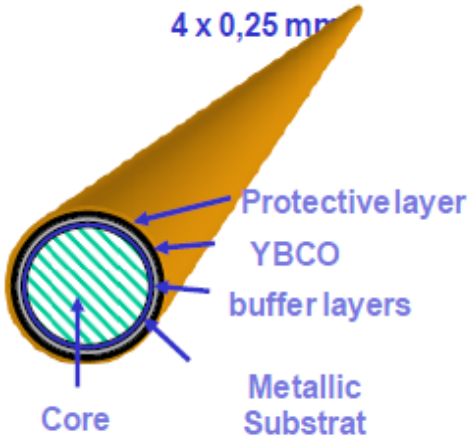
Superconducting materials

Superconducting tapes and wires for **current transportation**

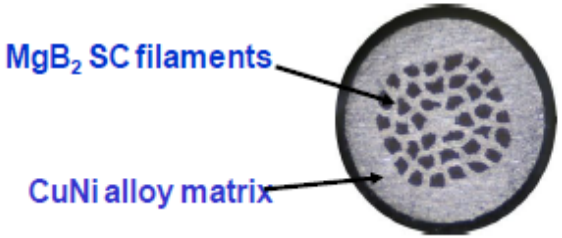
- 1st generation: multifilamentary Bi 2223 tapes (Top<77K)

- 2nd generation : YBCO Coated conductor tapes and wires (Top<77K)





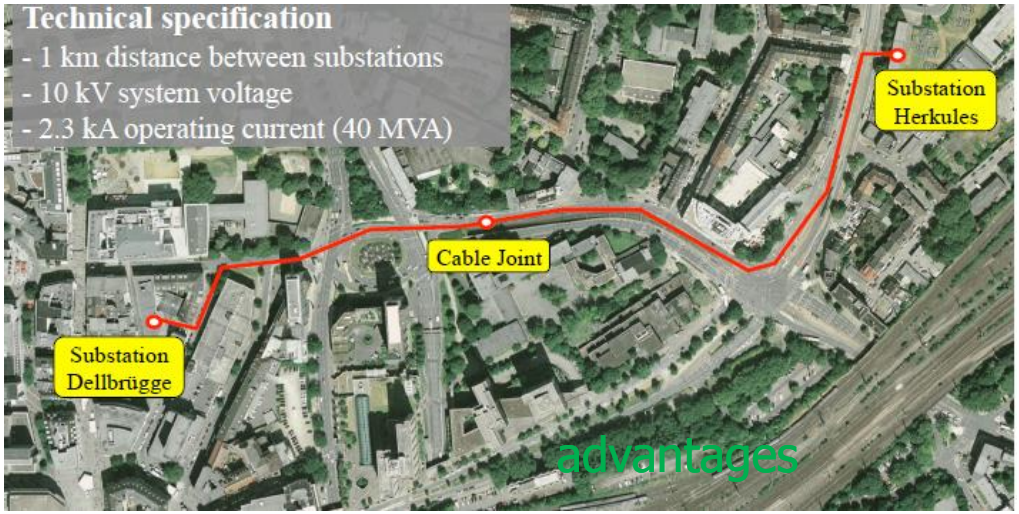
- MgB_2 wires (Top<30K)

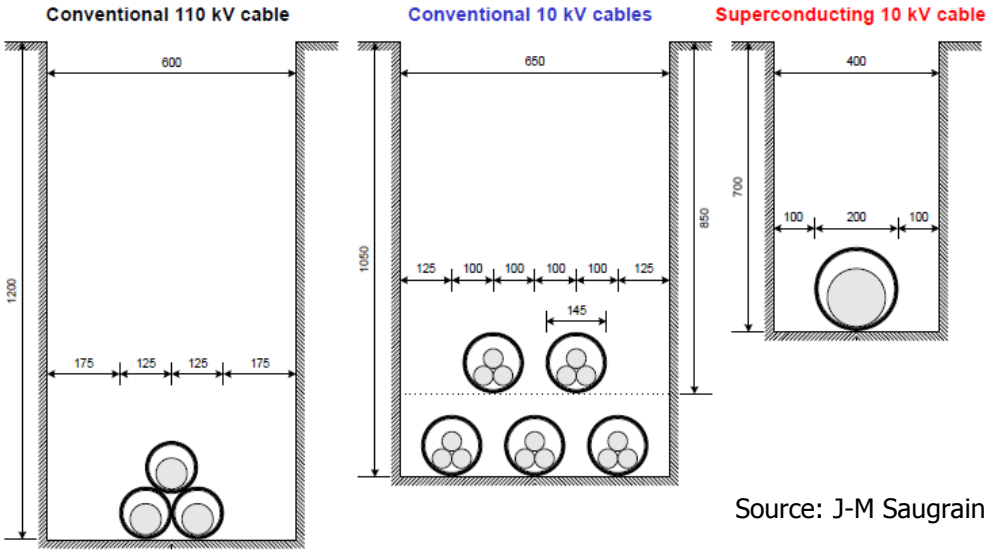


Material	Cost/(kA m) [$]	type
Al	3	Raw material
Cu	15	Raw material
Mg + B [@ 20 K, 1 T]	< 0.1	Raw materials
MgB_2 [@ 20 K, 1 T]	2 – 10	wire
HTS [@ 77 K, 1 T]	100-300	tapes

In-grid projects over the world (most HTS AC cables)

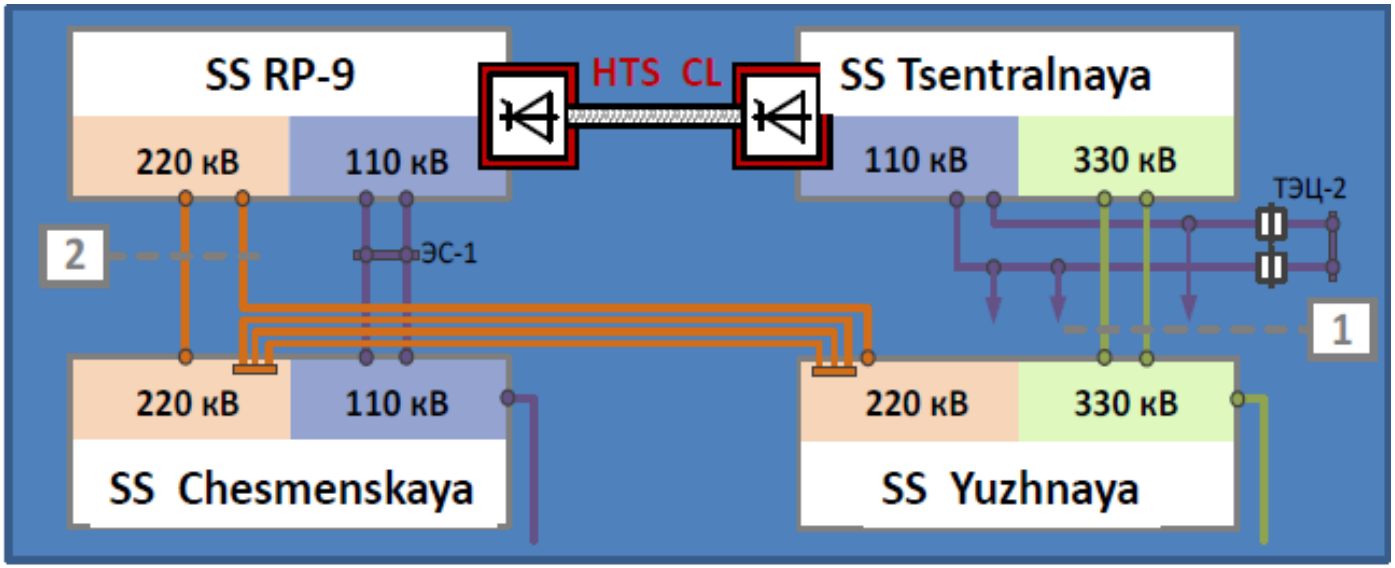
Project	Location	Length [m]	Capacity [MVA]	Schedule	Operator
LIPA	Long Island/USA	600	574 (138 kV AC, 2.4 kA)	In operation since 2008	LIPA
AmpaCity	Essen/Germany	1000	40 (10 kV AC, 2.3 kA)	Start of operation 01/2014	RWE
	Amsterdam/NL	6000	250 (50 kV AC)	Proposed	Alliander
St. Petersburg Project	St. Petersburg/Russia	2500	50 (20 kV DC, 2.5 kA)	Start of operation 2015	FGC UES[a]
Ishikari	Ishikari/Japan	2000	100 ($\pm$ 10 kV DC, 5 kA)	Start of construction spring 2014	City of Ishikari
	Icheon/Korea	100	154 (154 kV AC, 3.75 kA)	Operating since 11/2013	KEPCO[b]
	Jeju Island/Korea	1000	154 (154 kV AC, 3.75kA)	Operation 2015	KEPCO
	Jeju Island/Korea	500	500 (80kV DC)	Operation 2014	KEPCO
HYDRA	Westchester county/USA	170	96 (13.8 kV AC/4 kA)	Start of construction early 2014	ConEdison
	Yokohama/Japan	250	200 (66 kV AC, 5kA)	Operation stopped December 2013, continuation planned with new high-performance refrigerator 2015.	TEPCO[c]
	China	360	13 (1.3 kV DC, 10 kA)	Operation since 2011	IEE CAS[d]
REG[f]	Chicago/US	5 km	to be specified	Planning since 2014	ComEd[e]
Tres Amigas	New Mexico/US		750/5000	Postponed	Tres Amigas LLC





Source: J-M Saugrain

St. Petersburg HTS DC CL project

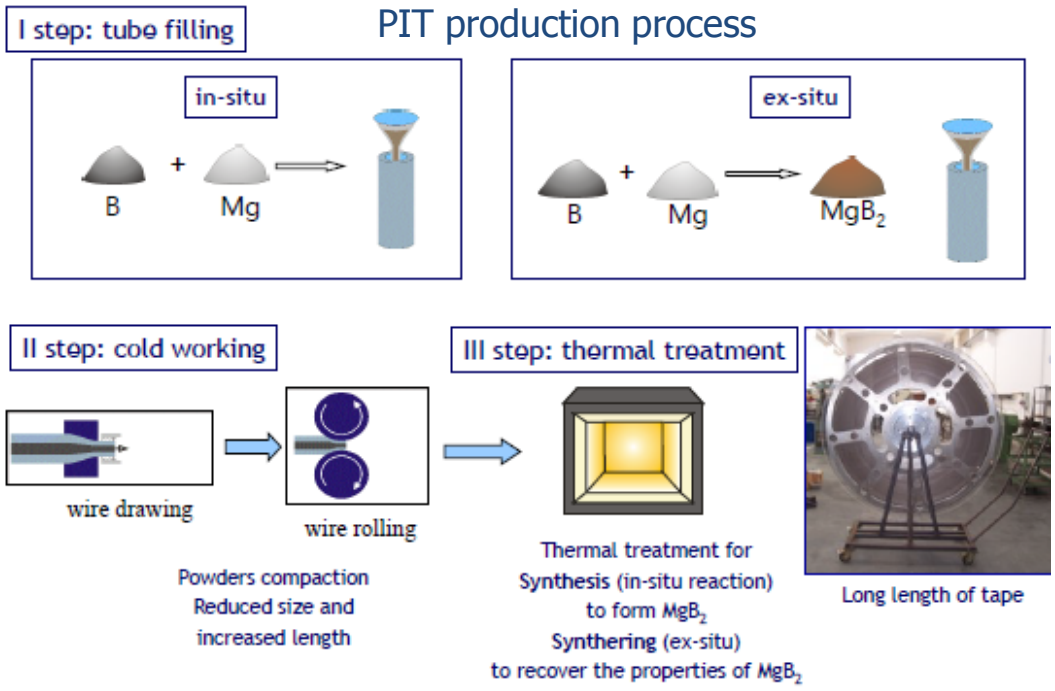


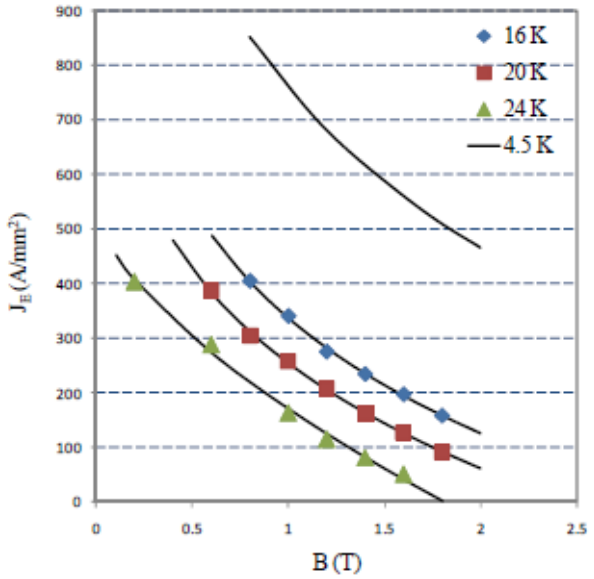
HTS DC Line Specification

Transmission power – 50 MW;
Operating current 2.5 kA;
Operating temperature 65 – 75K;
Operating voltage 20 kV
Length – about 2500 m

Source: Sytnikov

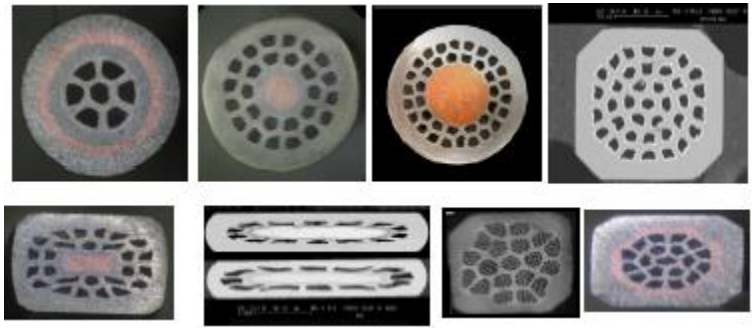
MgB2: unique properties in between LTS and HTS



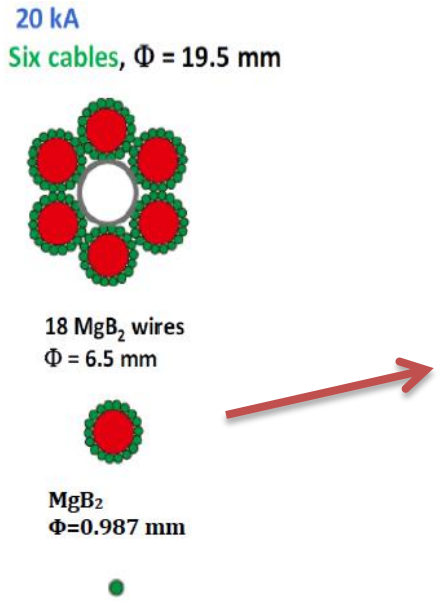


Source: A. Ballarino

- Up to 20 km unit length
- 4000 km/year capacity
- Flexibility in form

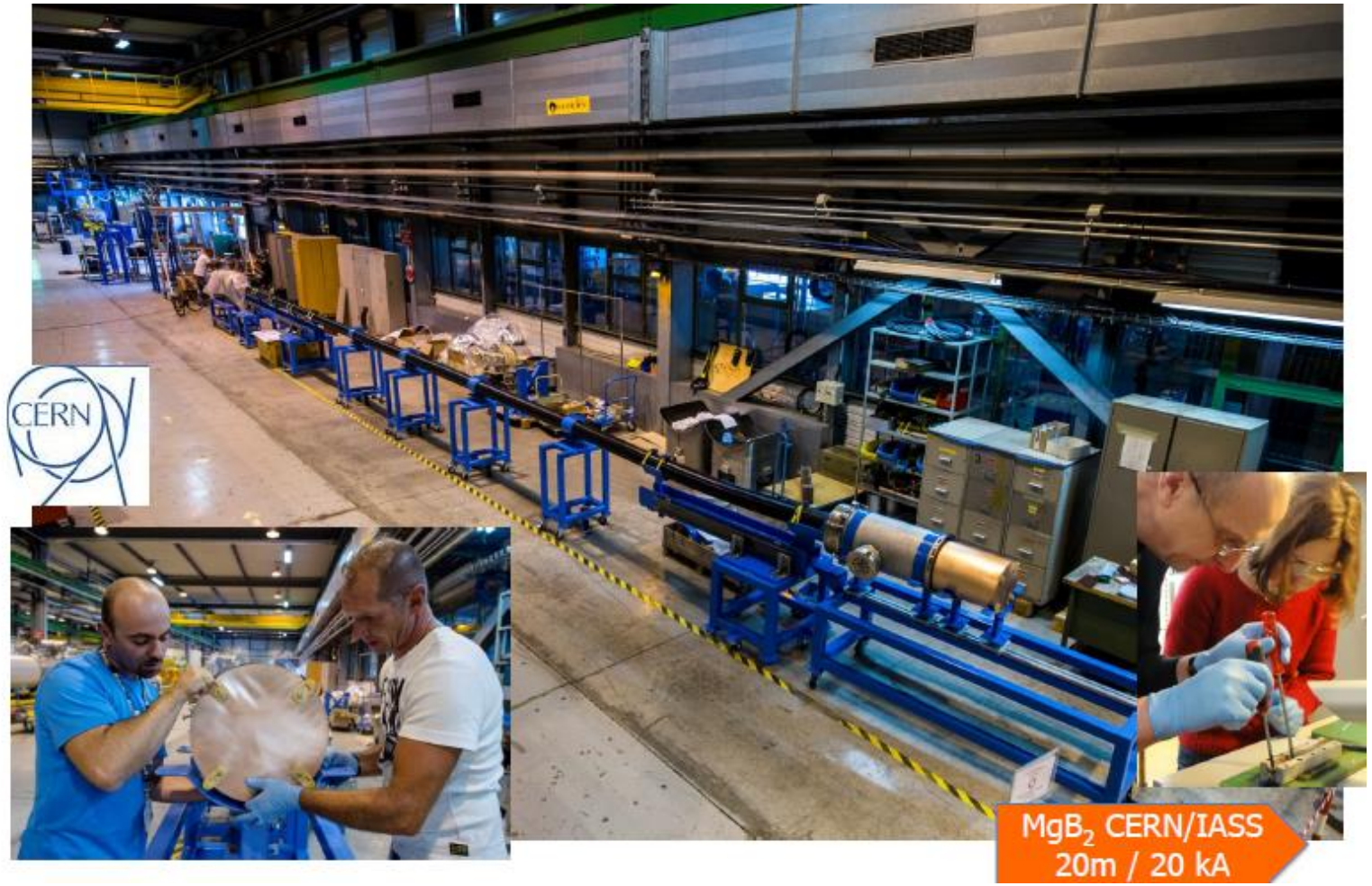


20 kA MgB2 power cable (CERN)



5 GW at 250 kV

20 kA MgB2 power cable (CERN)

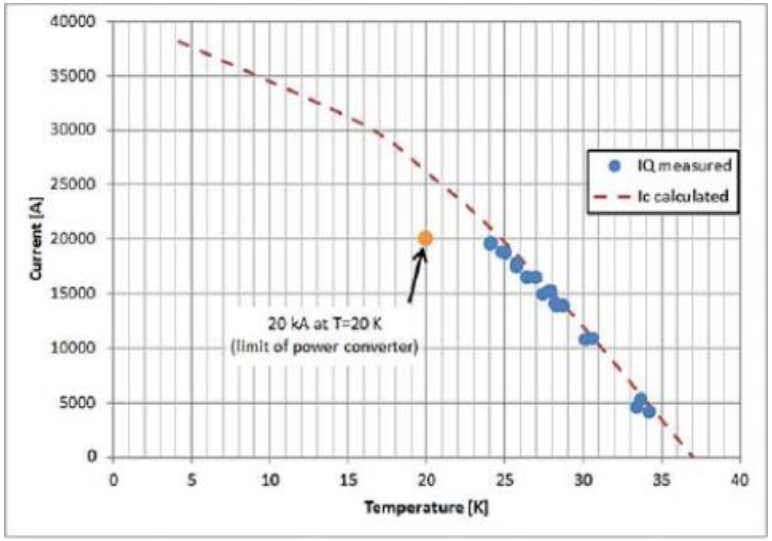


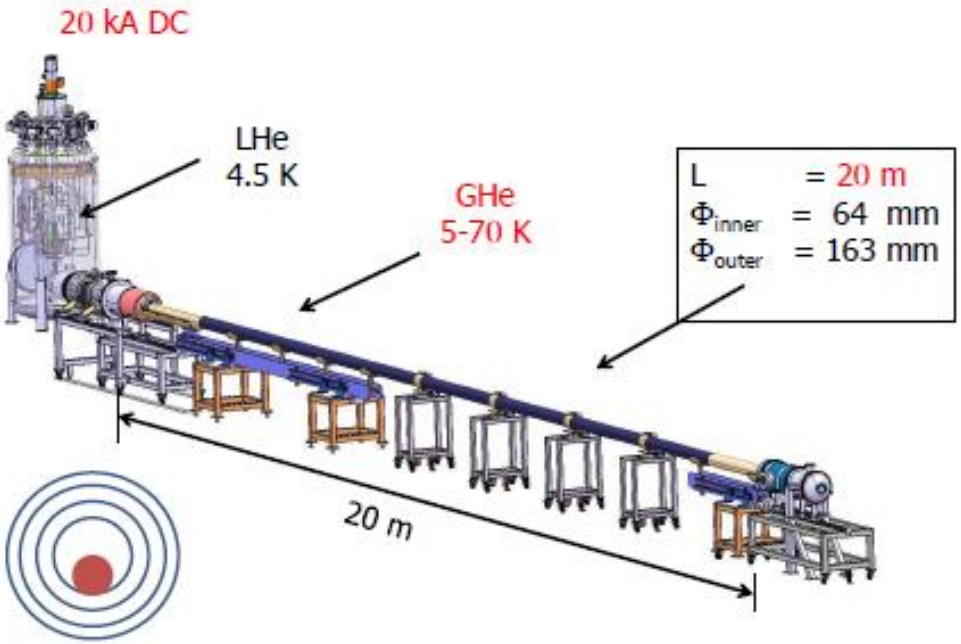
20 kA MgB2 power cable (CERN)

He cryostat

20 kA current leads

20 kA MgB2 power cable (CERN)

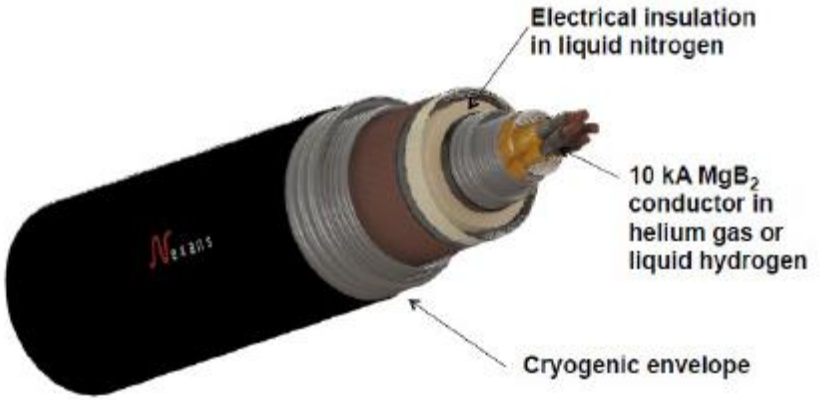




Source: A.Ballarino

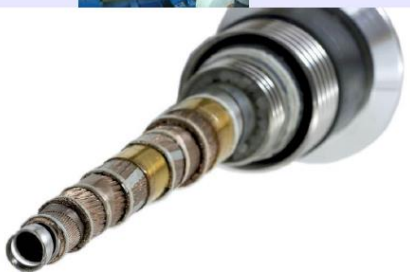
FP7 Best Paths (2014-2018)

Demo5: MgB2 DC power cable



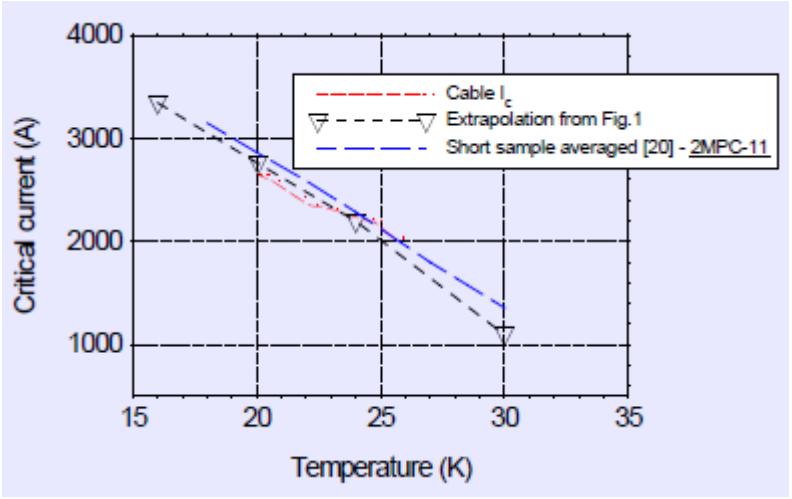
- Structure: Monopole
- Power: 3.2 GW
- Voltage: 320 kV DC
- Current: 10 kA
- Length: 30 m
- Cooling: He gas for MgB2 and LN2 for electrical insulation

30 m long MgB2 cable cooled by LH2 (VNIIKP, Moscow)



The cable has been made with standard cable equipment with technologies similar to those used for HTS cables.

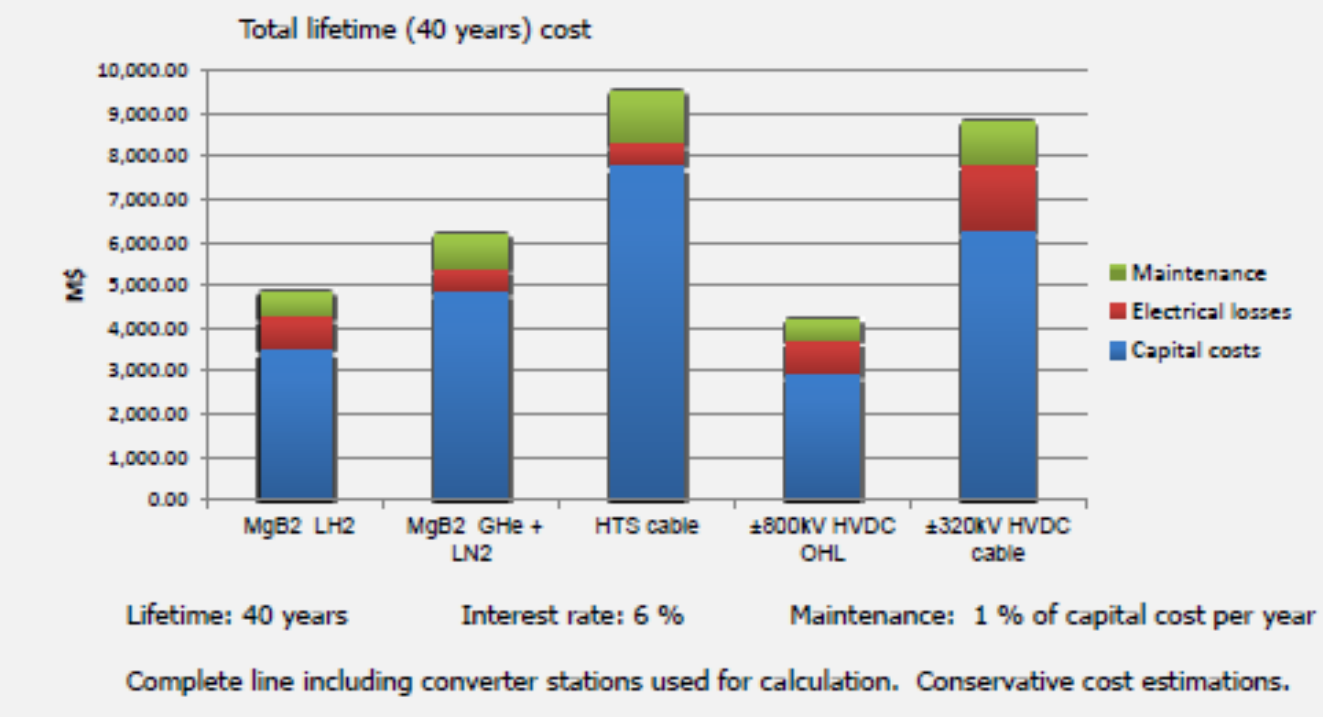
2 kA at 50 kV



Source: Vysotsky

Economic consideration

Südlink-Trasse (4 GW, 810 km)



Source: H. Thomas

Thank you for your attention !