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Hybrid Energy Transfer Line with Liquid Hydrogen and Superconducting MgB2 Cable – First Experimental Proof of Concept

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Background of the work

- **Energy** should be **not only produced but delivered** to the place of consuming
- It is being produced sometimes very far from the consuming area
- Distance could be could be hundreds and thousands kilometers
- It is transferred by an energy carrier

Energy carriers could be:

Gas, sometime LPG

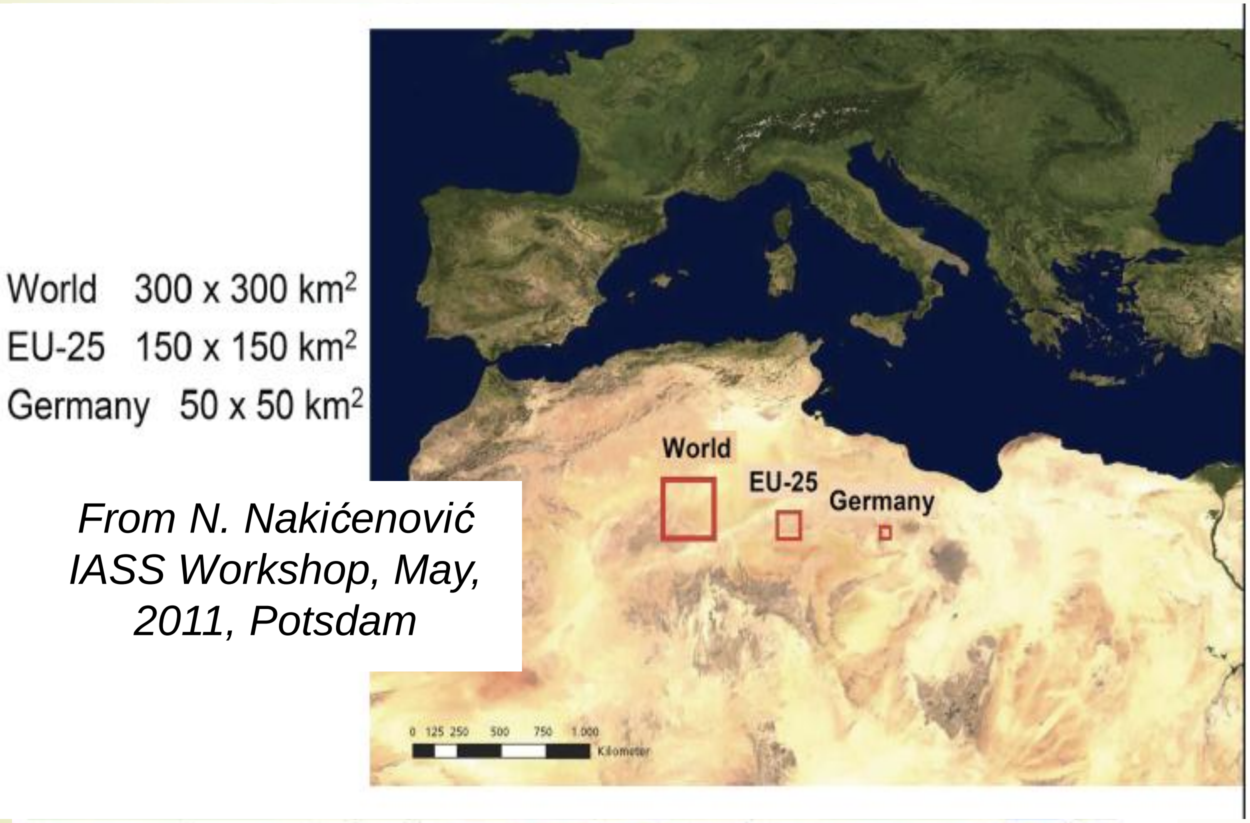
Oil

Electricity

Background of the work

Examples of the energy transferring routes

Solar energy in Sahara



From N. Nakićenović IASS Workshop, May, 2011, Potsdam

East Siberia for South-East Asia

Background of the work – electricity is the most common method for energy transfer

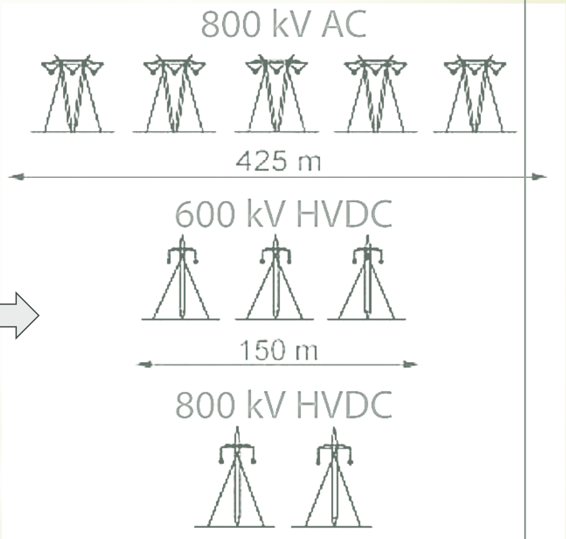
- HVDC overhead lines 750-800 кV Huge sizes

- Power density:

800 kV x ~1 kA ~ 0.8-1 GW

s~50 m x 100 m ~ 10^4 m^2

p~20 W/cm^2



From C.Rubbia IASS Workshop, May, 2011, Potsdam

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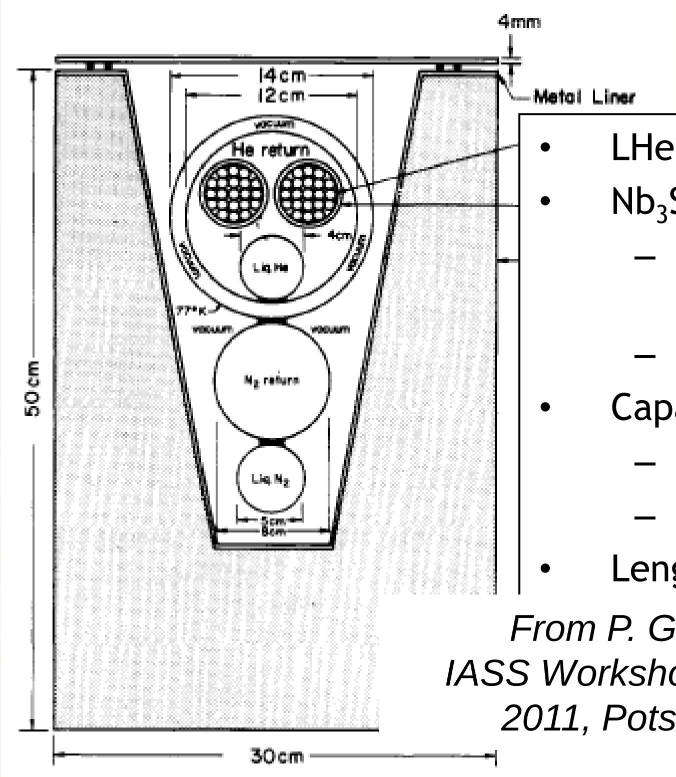
Background of the work – Superconductivity is the matter of choice to transfer electricity

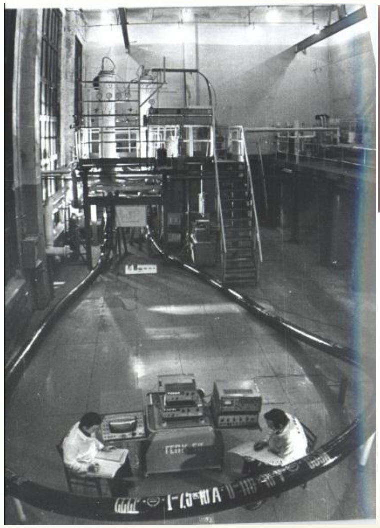
From the Garwin-Matisoo ideas



- LHe cooled
- Nb_3Sn (T_C = 18 K)
  - J_C = 200 kA/cm^2
  - H* = 10 T
- Capacity = 100 GW
  - +/- 100 kV dc
  - 500 kA
- Length = 1000 km

From P. Grant IASS Workshop, May, 2011, Potsdam

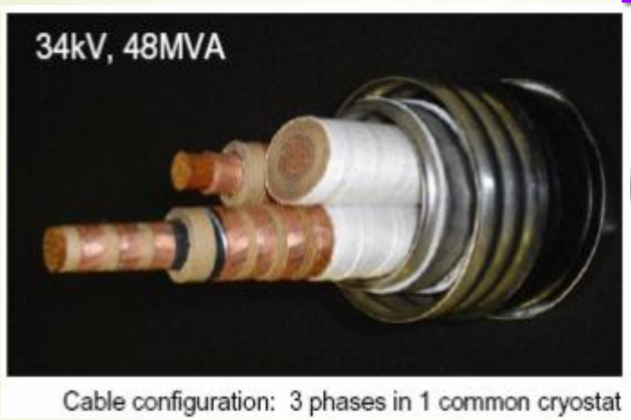
And early VNIIKP (and BNL) works with LTS

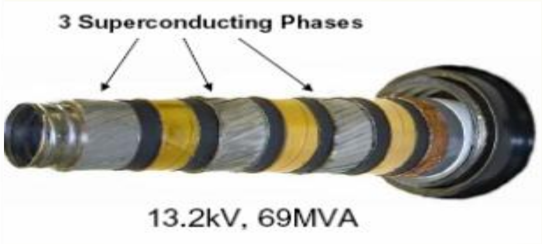


We are moving to HTS!!

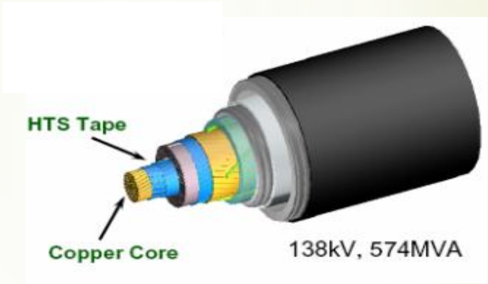
2LA-01, ASC - 2012, Oct. 2012, Portland (Or), USA

Background of the work – Superconducting HTS cables





Ultera-ORNL



Nexans-AMSC
~500 MVA

Sumitomo

Russia - VNIIKP

20 кV – 1.5/2 кA -50/70 MVA

~ 100-500 MVA; s~1000 cm^2

p~ $1 \div 5 \cdot 10^5$ W/cm^2

Usual cables – about the same sizes, but 20% of losses and less power density

Background of the work - Other energy carriers

- Oil and gas – traditional and it is clear about them
- LNG, T~150-160 K – we have no such superconductors ☹, **yet…**

"North Stream" gas pipeline: 27.5 $\cdot 10^9$ m^3/year; ~870 m^3/s; ~40 MJ/m^3 - 3.5$\cdot 10^{10}$ W; with s~18000 cm^2 (∅~150 cm) **p~2 · 10^6 W/cm^2**

- **What about hydrogen?**
- **120 MJ/kg – best fuel!**
- **Being liquid – best cryogen! 446kJ/kg against 20.3 kJ/kg for LH2 and 199 kJ/kg for LN2**
- **When burned – water is remained – best ecology!**
- **And could be transferred at liquid state at T~ 20-27 K!**
- **We DO HAVE superconductors for such temperatures!**

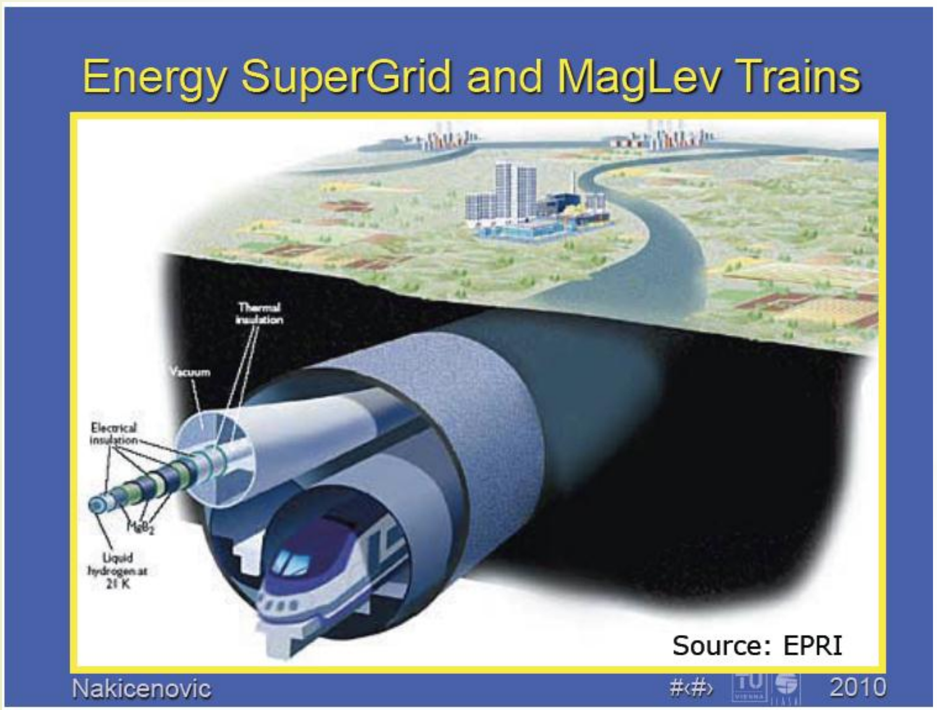
Why not use it after all?

2LA-01, ASC - 2012, Oct. 2012, Portland (Or), USA

Energy SuperGrid: hydrogen + superconducting cable = hydricity

- MgB$_2$ with single phase liquid hydrogen with or even without additional single phase N$_2$ coolant offers major simplifications with respect to classic Nb-alloys and boiling He + N$_2$, with practical distances of up to several hundred km.

C. Rubbia, ***"The future of large power electric transmission"***, available at: http://www.iass-potsdam.de/fileadmin/user_upload/Rubbia_presentation.pdf



Old and long time discussed idea.
Of course it is may be a bit exotic and may be for the day far after tomorrow.
But in any case sometimes it should be started and we somebody should go to practical realization of this.

And we got some practical results !!

Our project is to proof EXPERIMENTALLY the concept of: Energy transfer with liquid hydrogen and superconducting cable - hybrid energy transfer system

Experimental tasks

- ❑ To chose the proper superconductor
- ❑ To develop and make superconducting cable with it
- ❑ To develop and produce liquid hydrogen cryogenic line with test facility
- ❑ To insert a cable inside cryogenic line and connect to cryogenics and electricity
- ❑ Bring to a site with liquid hydrogen
- ❑ Make tests…

MAJOR GOALS WERE TO UNDERSTAND:

- ❑ *What is MgB_2, its manufacturability and how to work with it*
- ❑ *How to make LH_2 cryostat and current leads and to learn how to work with LH_2 (see:* "First in the world prototype of the hydrogen – superconducting energy transport system", *Proceedings of ICEC 24-ICMC 2012*, Fukuoka, Japan, May 2012, *in press)*
- ❑ *To get the <u>first experimental data</u> about <u>hybrid energy transport systems</u> (HETL)*

Superconductor's choice

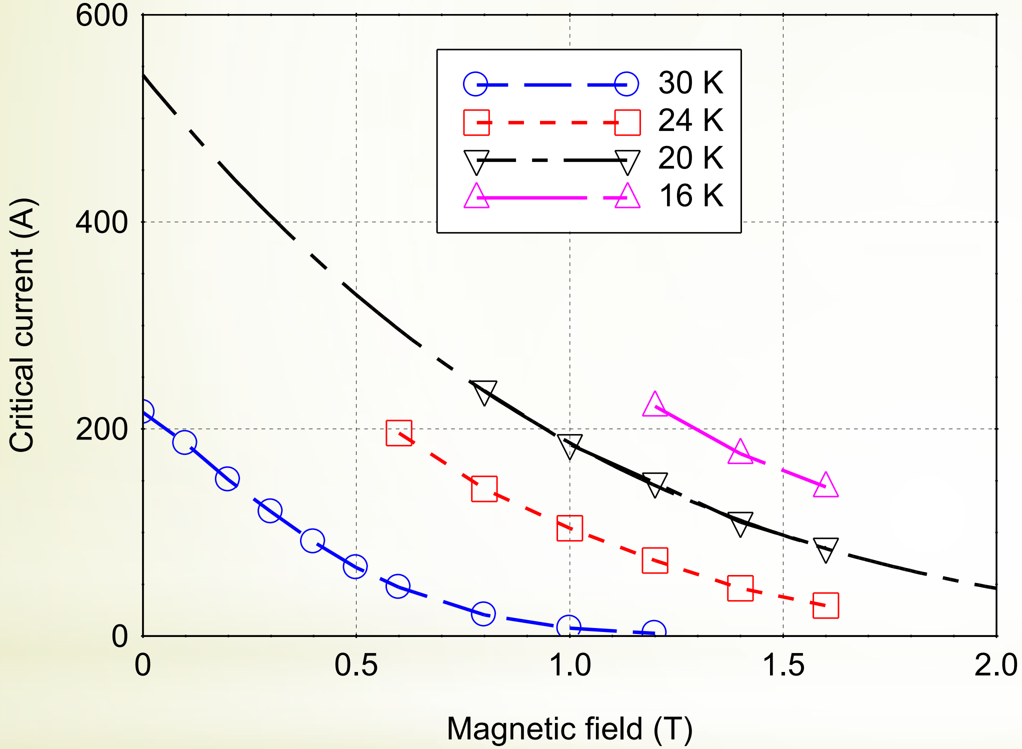
Type - Superconducting technology	Basic material, T_c	Cryogen and its temperature	Prices US$ per 1кА·м
LTS – metallurgy	NbTi - alloy ~ 10K	Liquid helium at 4.2 К and below	Up to 3-5$ @ 4.2 К
LTS – metallurgy	Nb_3Sn – compound ~ 18 K	Helium up to 8-10 К and below	Up to 15$ @ 4.2К
HTS 1 generation (Powder in tube – metallurgy)	Ceramic $Bi_2Sr_2Ca_{n-1}Cu_nO_{2n+4}$ (Bi-2223,Bi-2212) ~90-110 K	Liquid nitrogen at 77 К and below (with other cryogens)	About 120-150$ @ 77 К About 40-50$ @ 20 К
HTS 2 generation (Long coated conductors - electronics)	Ceramic $YBa_2Cu_3O_{7-d}$ ~90 K	Liquid nitrogen at 77 К and below (with other cryogens)	About 300-500$ @ 77К About 80-150$ @ 20К
Magnesium diboride - (Powder in tube – metallurgy)	MgB_2 – compound ~39 K	Liquid hydrogen and below (with other cryogens)	About 5$ @ 20 К

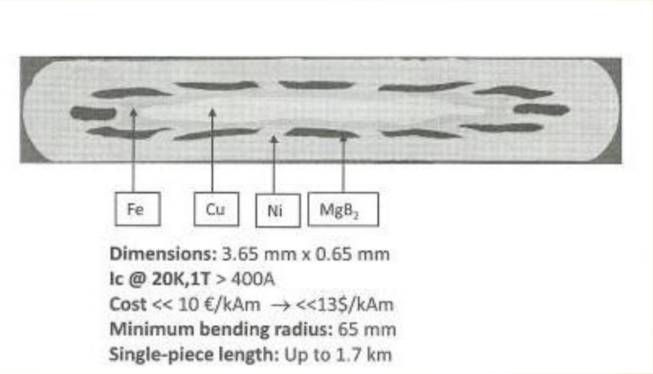
Magnesium diboride: now available, has high parameters (overall current density about 2-7·10^4 A/cm^2 at LH_2 temperatures) and most important:

pretty cheap!

Superconductor's choice

Flat wire has been selected to use technology developed for HTS power cable made of BSCCO tapes





Basic tape: 3.65мм x0.65 мм MgB_2, Fe barrier, Ni matrix, Cu stabilizer Produced by Columbus superconductor , Genoa, Italy

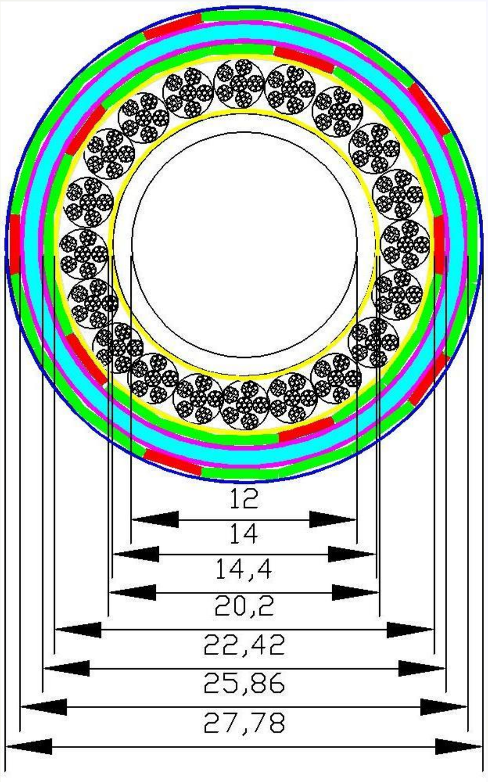
Estimated: I_c (20 К, s.f.) ~520-540 A
Good stability at 20 K

Data from: **http://www.columbussuperconductors.com**

Later we studied Ic(T) for short wires – you could see our poster 2MPC-11 this morning

2LA-01, ASC - 2012, Oct. 2012, Portland (Or), USA

Superconducting cable



Cable: five tapes, two layers, total length 10 м, copper stabilization ~90 мм^2 for each layer

Insulation – 10 layers of Kapton, δ~1 мм, estimated as enough for 20-40 кV

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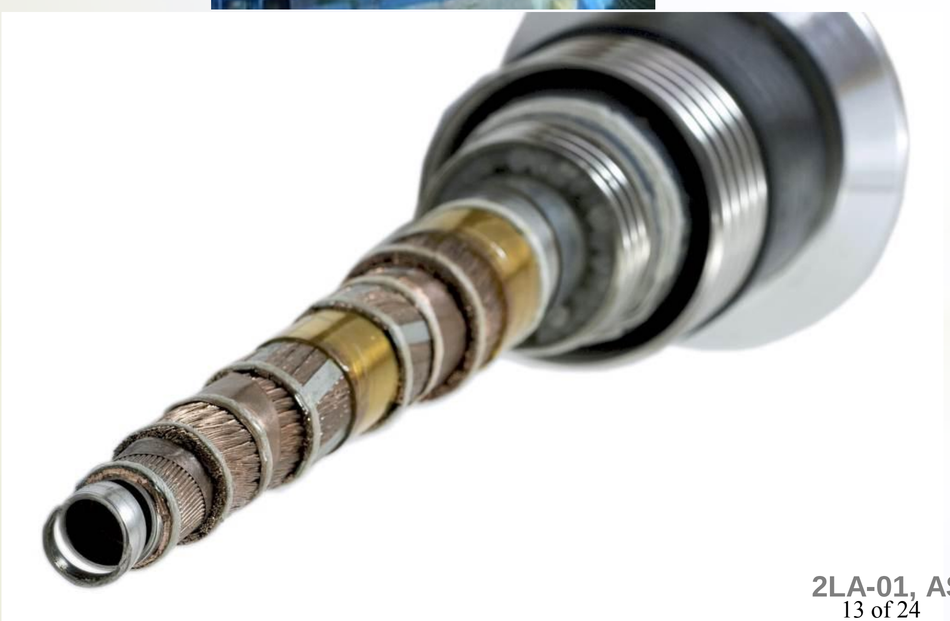
Superconducting cable

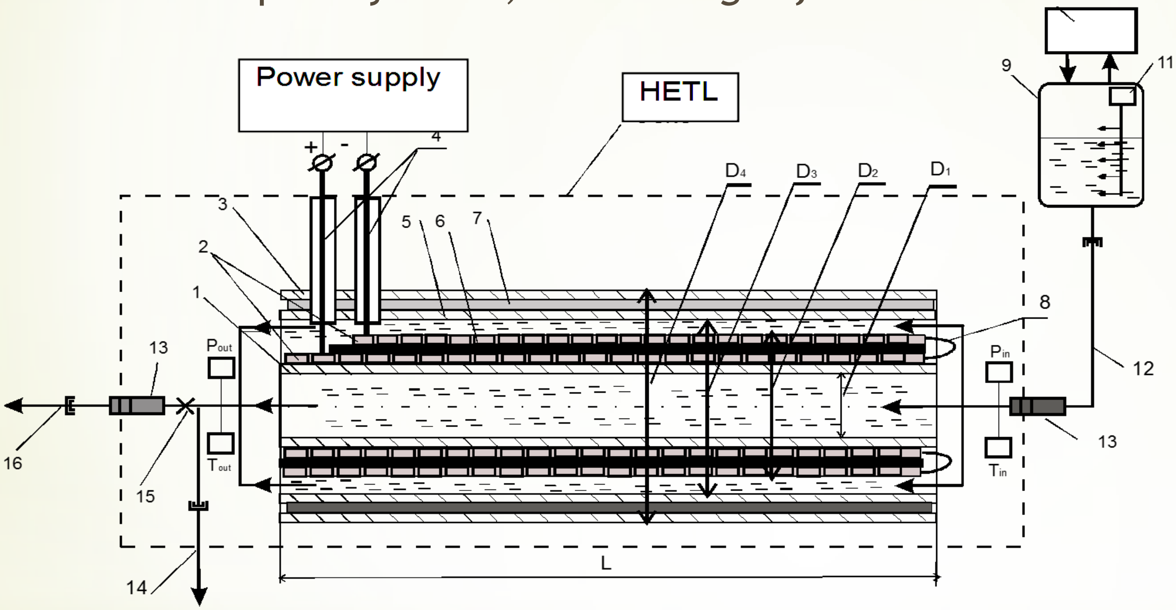


The cable has been made with standard cable equipment with technologies similar to those used for HTS cables.

Test facility and cryostat

Developed by MAI (schematic view)

Details in: "First in the world prototype of the hydrogen – superconducting energy transport system", *Proceedings of ICEC 24-ICMC 2012*, Fukuoka, Japan, May 2012,

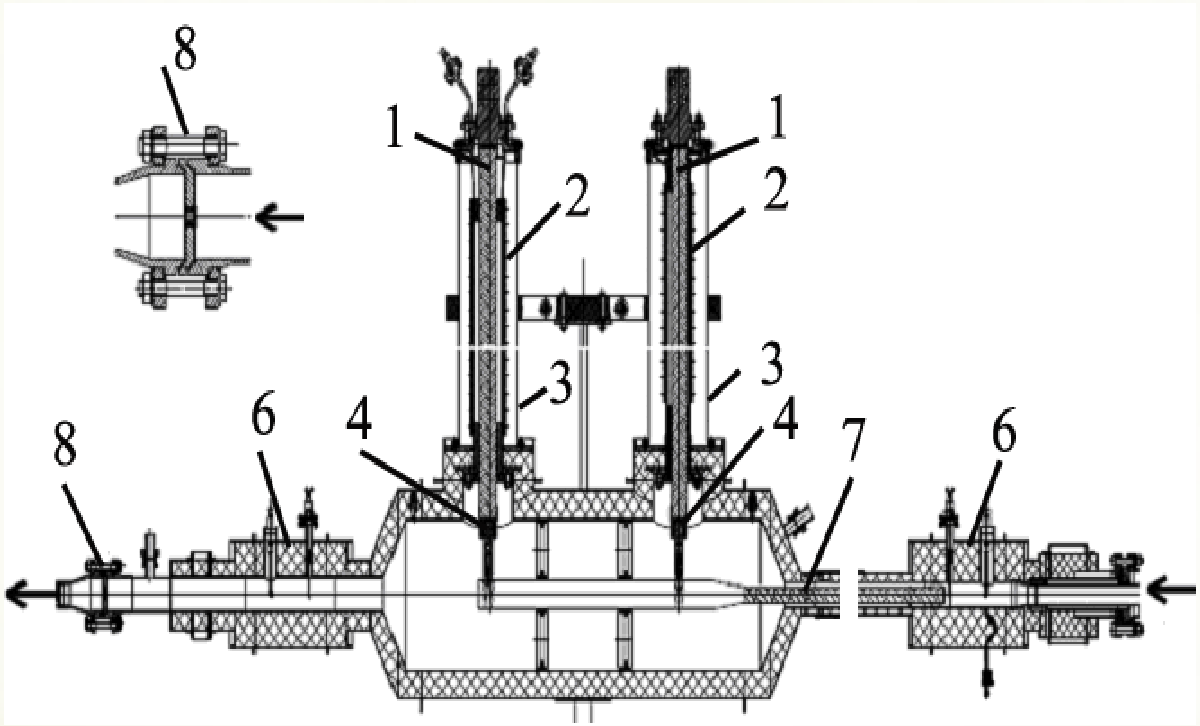


1- former; 2 – current carrying superconductors; 3 – outer tube of cryostat; 4 – current leads; 5 – inner tube of the cryostat; 6 – polyimide; 7 – layered super-insulation; 8 – current jumpers; 9 – liquid hydrogen storage tank; 10 – filling, pressure busting and drainage systems; 11 – level meter and temperature sensors; 12 – flexible liquid hydrogen 12 m transfer line; 13 – bayonet connectors ∅ = 32 мм; 14 – drainage 4 m flexible line ∅ =32 мм; 15 – jet nozzle ∅= 4 mm; 16 – drainage flexible line ∅ =32 мм

Inner diameter 40 mm, outer 80 mm; Vacuum Super-Insulation; Four sections with safety diaphragms; Nozzles to regulate LH2 flow

Current leads

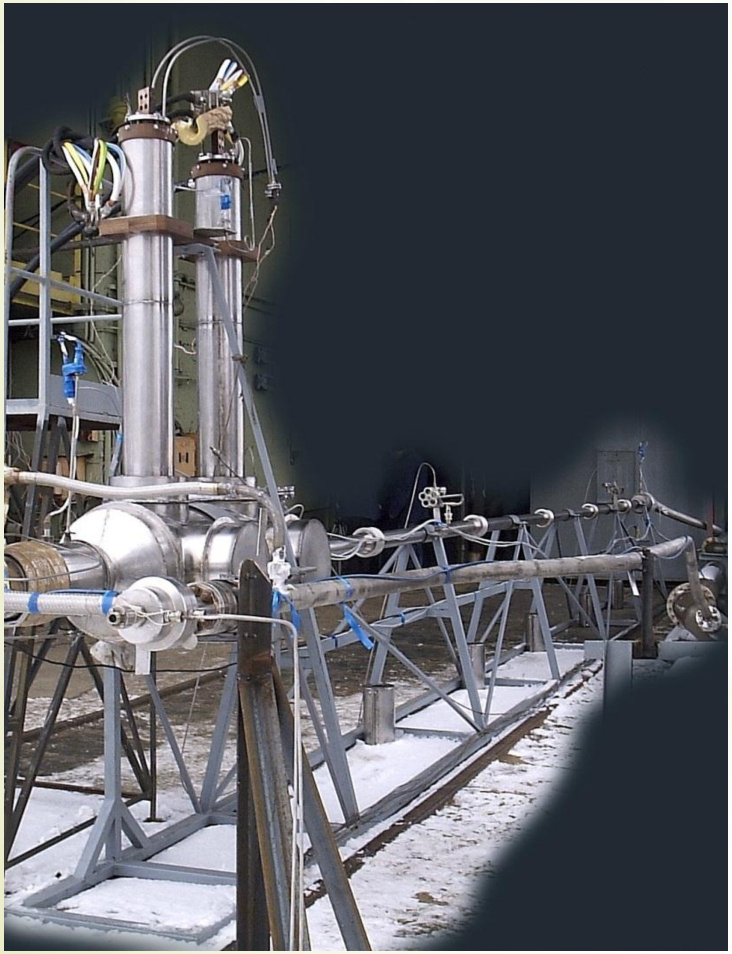
Developed by MAI



1 – current pathway; 2 – insulating polyimide tube with outer bandages; 3 – load bearing support; 4 – connection of the joint with a cable; 5 – getter; 6 – measuring probes; 7 – connections of flexible copper bunches and superconductors; 8 – mounting part.

Ratings: ~3-4 кA and voltage ~20кV.

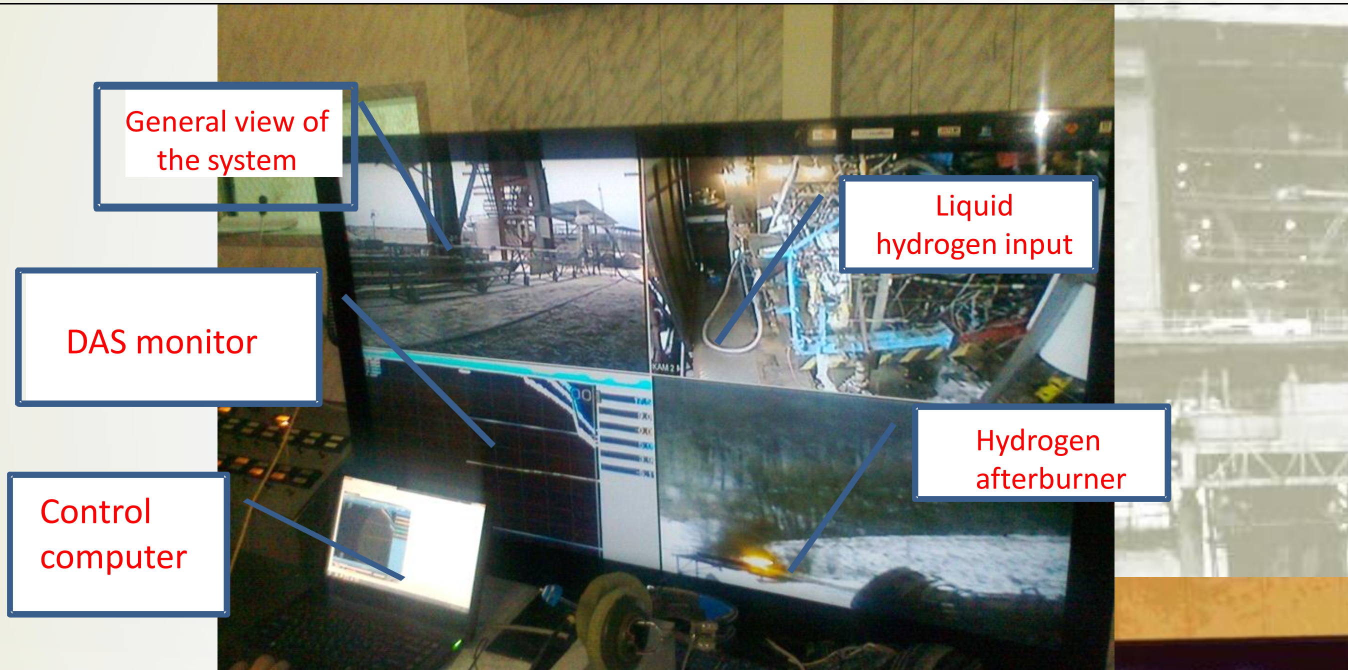
General view of the hybrid energy transport system



Tests at the DBCA, November 2011

КБХА

Tests process



Cryogenics test results were presented before at ICEC-24

Total cooling time ~380 s.

To cool the system it was used ~ 2.3 kg of LH_2.

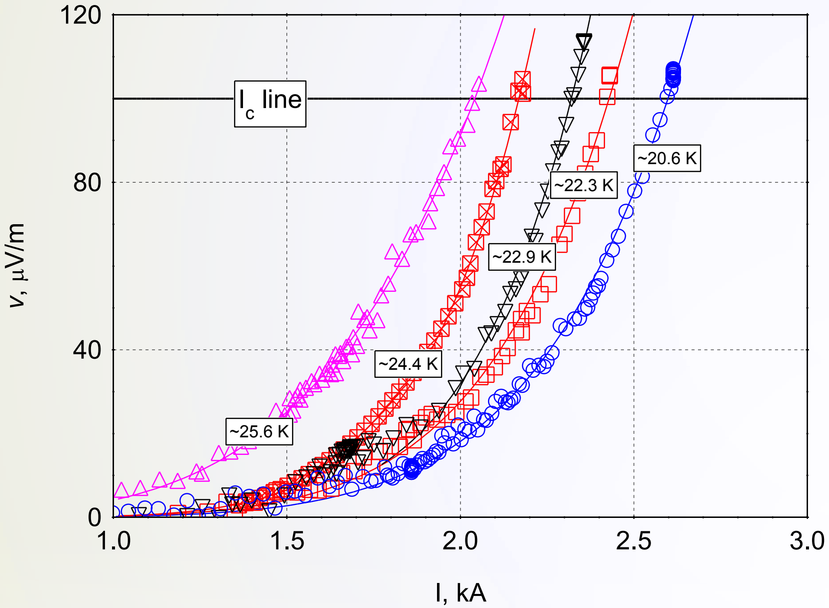
Estimated heat losses were below 10±2 W/m (good for LH_2), current lead losses at 2600 A~300 W.

Temperature at measurements were form 20 К to 26 K, pressures from 0.12 to 0.5 MPa

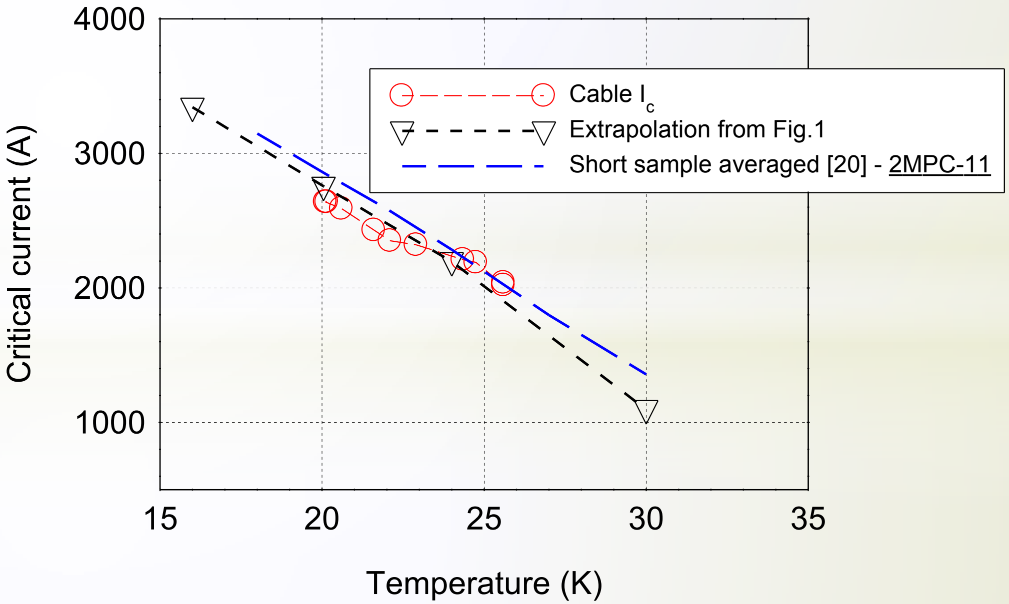
Temperatures variations along a cable from 0.2 K to 0.8 K depending on flow rate

LH2 flow from 10 g/s to 250 g/s.

Test results - superconductivity



V-I characteristics at different temperatures have been measured
Data about critical current were obtained



Ic(T) dependence

Data from wire supplier and from measurements of short samples coincides well with cable's data.

CONCLUSIONS - I

- Liquid hydrogen cryogenic line with special current leads has been developed – **works well**
- MgB2 from Columbus Superconductor has a good manufacturability and could be used for industrial cable production.
- **Superconducting parameters are good as well**
- Developed, produced and tested **MgB2 superconducting cable** with 10 m length with currents ~ **2000-2600 A.**
- **First hydrodynamic and superconducting data** of the hybrid energy transport system **has been obtained**

CONCLUSIONS - II

- With LH_2 flow **250 g/s** – the delivering power is **~31 MW**.
- Superconducting cable at **2.5 кA** and 20 kV – is able to deliver extra **50 MW**, so **80 MW** in total with only 5 tapes
- It is easy to add five or ten tapes more and we can increase electrical power to 100 – 150 MW and total power to 130 - 180 MW.
- Therefore, **the energy transfer line tested is able to deliver energy flow more than 100 MW**

CONCLUSIONS - III

We tested first in the world experimental prototype hydrogen + superconducting energy transporting system

The conception of hybrid energy transport system has been proved

From this real experiment we can get data that permit to make evaluations and to plan the next developments. Our nearest plans: longer flexible line, high voltage test, more hydrodynamic and superconducting data

Thank you for your attention !